State of California
The Resources Agency
Department of Water Resources

FINAL REPORT EVALUATION OF SPAWNING AND INCUBATION SUBSTRATE SUITABILITY FOR SALMONIDS IN THE LOWER FEATHER RIVER SP-F10, TASK 2A

Oroville Facilities Relicensing FERC Project No. 2100

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REPORT SUMMARY

The purpose of SP-F10 Task 2A was to evaluate spawning and incubation substrate suitability for salmonids in the lower Feather River. Ongoing operation of the Oroville Facilities has the potential to influence the size structure of available gravels, recruitment of gravels, intragravel water temperatures, and intragravel dissolved oxygen concentrations in the lower Feather River, which in turn, affects Chinook salmon and steelhead spawning and embryo incubation substrate suitability. The results from this study would be used to evaluate future potential resource actions involving facility operations and potential effects to substrate suitability to the spawning and embryo incubation life stage of Chinook salmon and steelhead.

The objectives of SP-F10 Task 2A were accomplished by collecting intragravel and bulk gravel data. Intragravel variables included permeability, dissolved oxygen concentration, water temperature, and the upwelling and downwelling potential. Intragravel data were recorded at 15 riffles in the lower Feather River from August 6, 2003 through November 13, 2003. Bulk gravel samples were collected at 20 riffles in the lower Feather River from October 2, 2002 through September 18, 2003. The results from the intragravel sampling generally did not apply to steelhead because data were collected outside of dates coinciding with presence dates for the steelhead spawning and embryo incubation life stage.

Results suggested that intragravel permeability and dissolved oxygen concentration were within suitable ranges, based on available literature. Intragravel water temperatures were below 56°F (13.3°C) from September 10, 2003 through November 13, 2003. Agreement exists within available literature and regulatory documents that water temperatures below 56°F (13.3°C) are suitable for incubating salmonids embryos. Upwelling or downwelling currents were detected in 86 percent of samples collected within Chinook salmon redds, suggesting that intragravel flow, regardless of the direction of the vertical hydraulic gradient, is the critical variable associated with spawning site selection by Chinook salmon in the lower Feather River. Based on available literature, intragravel permeability, dissolved oxygen concentration, water temperature, and upwelling and downwelling currents, during the time period that data were collected, likely did not limit survival of incubating salmonid embryos in the lower Feather River.

Results from gravel size distribution curves, armor index values, and the geometric sorting index suggested that surface strata in the lower Feather River are coarse, and that armoring is particularly evident in the LFC. Subsurface sample gravel size distributions were similar between the LFC and HFC. The median gravel diameter (D_{50}) of surface samples suggested that gravels in the LFC generally are too large for successful redd construction by Chinook salmon. The gravel size distribution suitability for spawning Chinook salmon generally increased with distance downstream from Oroville Dam. Fine sediment analyses (gravels <6 mm diameter) suggested that fine

sediments within gravels in the lower Feather River were suitable for incubating Chinook salmon and steelhead embryos, and likely did not limit the percentage of embryos surviving through emergence.

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1.0 INTRODUCTION

1.1 BACKGROUND INFORMATION

Ongoing operation of the Oroville Facilities has the potential to influence the size structure of available gravels, recruitment of gravels, intragravel water temperatures, and intragravel dissolved oxygen concentrations in the lower Feather River, which in turn, affects spawning and embryo incubation substrate suitability. As a component of study plan (SP)-F10, *Evaluation of Project Effects on Salmonids and Their Habitat in the Feather River Below the Fish Barrier Dam*, Task 2 of SP-F10 evaluates project effects on the spawning, incubation and initial rearing period of salmonids in the Feather River. Task 2A, herein, evaluates spawning and embryo incubation substrate suitability for salmonids in the Feather River.

1.1.1 Statutory/Regulatory Requirements

The purpose of SP-F10 Task 2A is to evaluate spawning and incubation substrate suitability for salmonids in the lower Feather River. Anadromous salmonids present in the lower Feather River include spring-run Chinook salmon (*Oncorhynchus tshawytscha*), fall-run Chinook salmon (*O. tshawytscha*), and steelhead (*O. mykiss*). On September 16, 1999, naturally-spawned Central Valley spring-run Chinook salmon were listed as threatened under the federal Endangered Species Act (ESA) by the National Marine Fisheries Service (NOAA Fisheries) (NOAA Fisheries 1999). The Central Valley spring-run Chinook salmon Evolutionarily Significant Unit (ESU) includes all naturally-spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries, which includes naturally-spawned spring-run Chinook salmon in the lower Feather River (NOAA Fisheries1999). On March 19, 1998, naturally-spawned Central Valley steelhead were listed as threatened under the federal ESA by NOAA Fisheries (NOAA Fisheries 1998). The Central Valley steelhead ESU includes all naturally-spawned populations of steelhead in the Sacramento and San Joaquin rivers and their tributaries, which includes naturally-spawned steelhead in the lower Feather River (NOAA Fisheries1998).

The results and recommendations from this study fulfill, in part, statutory and regulatory requirements mandated by the ESA as it pertains to Central Valley spring-run Chinook salmon and steelhead. In addition to the ESA, Section 4.51(f)(3) of 18 CFR requires reporting of certain types of information in the Federal Energy Regulatory Commission (FERC) application for license of major hydropower projects, including a discussion of the fish, wildlife, and botanical resources in the vicinity of the project (FERC 2001). The discussion is required to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact for on-going and future operations. As a subtask of SP-F10, Task 2A fulfills a portion of the FERC application requirements by evaluating spawning and incubation substrate suitability for salmonids in the lower Feather River. In addition to fulfilling these requirements, information collected during this task may be used in developing or evaluating potential Resource Actions.

1.1.2 Study Area

1.1.2.1 Description

The study area in which the results of Task 2A of SP-F10 apply includes the reach of the lower Feather River extending from the Fish Barrier Dam at RM 67.25 downstream to Herringer Riffle at approximately RM 46 (Figure 1.1-1). In general, the majority of spawning habitat available in the lower Feather River is located in this stretch of river. Two distinct reaches exist within the lower Feather River: the upstream reach, and the downstream reach. The upstream reach extends from the Fish Barrier Dam downstream to the Thermalito Afterbay Outlet (RM 59), and is referred to as the LFC. The downstream reach extends from the Thermalito Afterbay Outlet downstream to the confluence with the Sacramento River (RM 0), and is referred to as the HFC. For purposes of this report, the HFC extends from the Thermalito Afterbay Outlet downstream to Herringer Riffle. The flow regimes associated with each reach are distinct, and are summarized in Section 1.3.1.1 below.

1.2 DESCRIPTION OF FACILITIES

The Oroville Facilities were developed as part of the State Water Project (SWP), a water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants. The main purpose of the SWP is to store and distribute water to supplement the needs of urban and agricultural water users in northern California, the San Francisco Bay area, the San Joaquin Valley, and southern California. The Oroville Facilities are also operated for flood management, power generation, to improve water quality in the Delta, provide recreation, and enhance fish and wildlife.

FERC Project No. 2100 encompasses 41,100 acres and includes Oroville Dam and Reservoir, three power plants (Hyatt Pumping-Generating Plant, Thermalito Diversion Dam Power Plant, and Thermalito Pumping-Generating Plant), Thermalito Diversion Dam, the Feather River Fish Hatchery and Fish Barrier Dam, Thermalito Power Canal, Oroville Wildlife Area (OWA), Thermalito Forebay and Forebay Dam, Thermalito Afterbay and Afterbay Dam, and transmission lines, as well as a number of recreational facilities. An overview of these facilities is provided on Figure 1.2-1. The Oroville Dam, along with two small saddle dams, impounds Lake Oroville, a 3.5-million-acre-feet (MAF) capacity storage reservoir with a surface area of 15,810 acres at its normal maximum operating level.

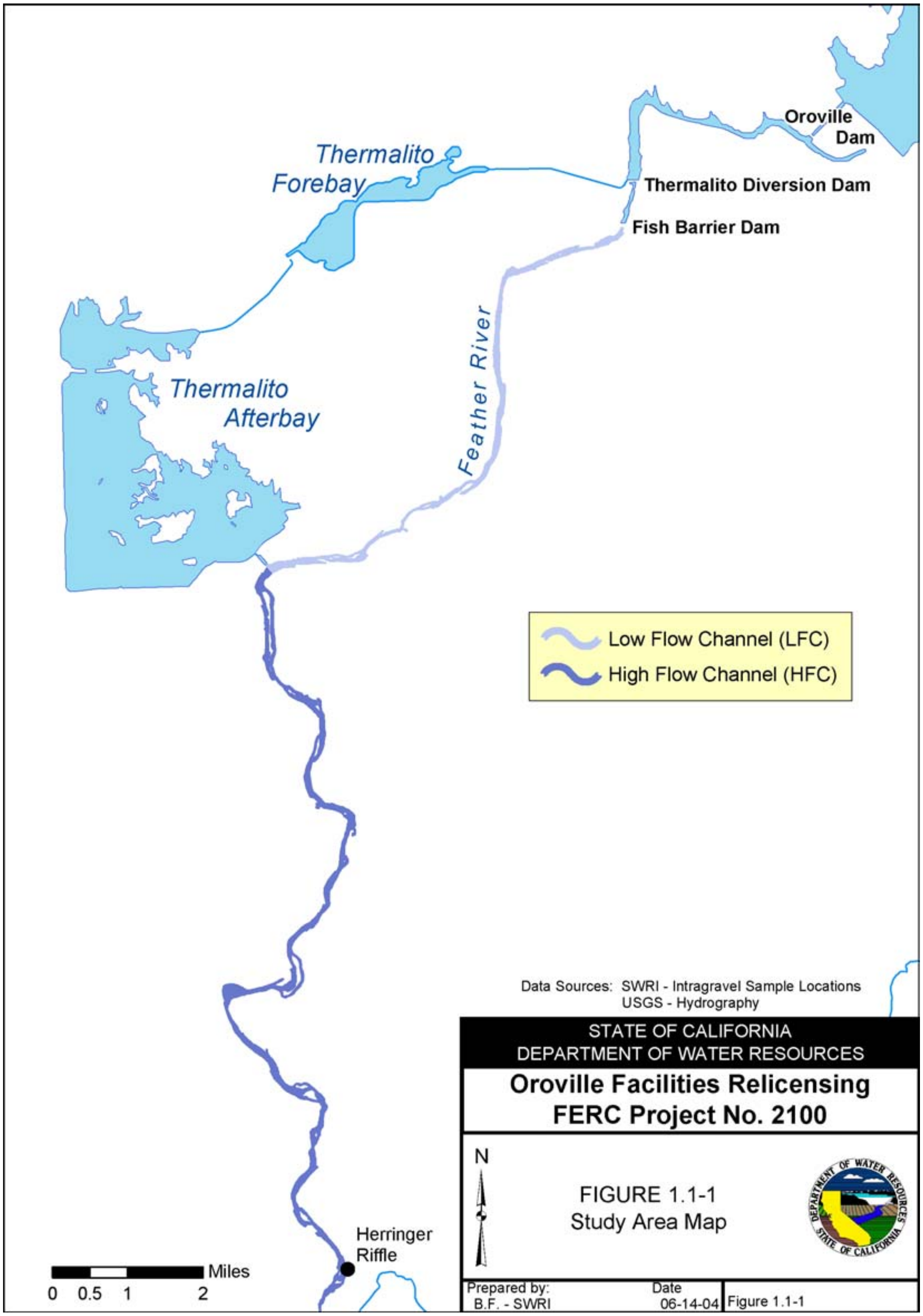

Figure 1.1-1. Study area for the bulk gravel and intragravel sampling.

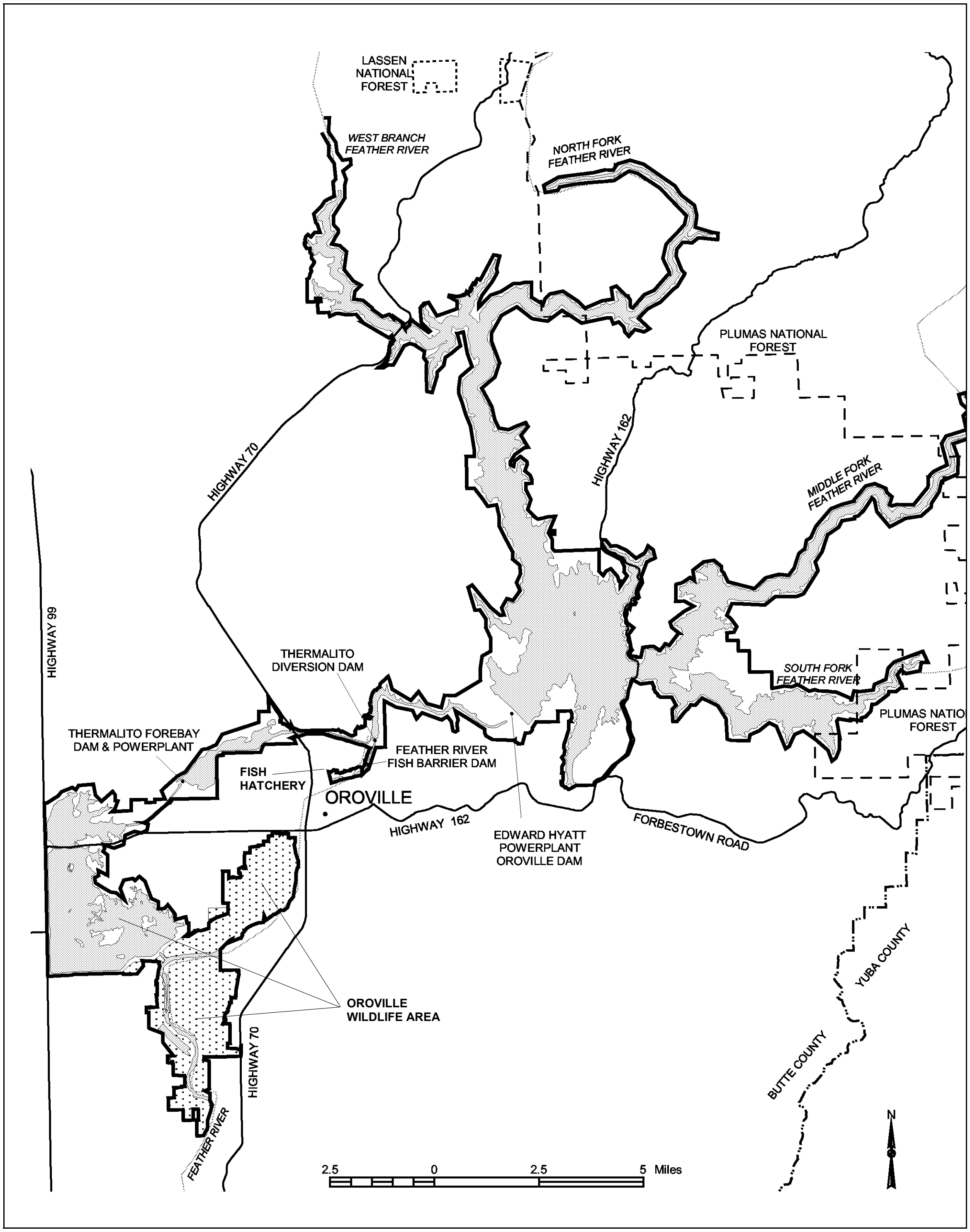

Figure 1.2-1. Oroville Facilities FERC Project Boundary.

The hydroelectric facilities have a combined licensed generating capacity of approximately 762 megawatts (MW). The Hyatt Pumping-Generating Plant is the largest of the three power plants with a capacity of 645 MW. Water from the six-unit underground power plant (three conventional generating and three pumping-generating units) is discharged through two tunnels into the Feather River just downstream of Oroville Dam. The plant has a generating and pumping flow capacity of 16,950 cfs and 5,610 cfs, respectively. Other generation facilities include the 3-MW Thermalito Diversion Dam Power Plant and the 114-MW Thermalito Pumping-Generating Plant.

Thermalito Diversion Dam, four miles downstream of the Oroville Dam, creates a tail water pool for the Hyatt Pumping-Generating Plant and is used to divert water to the Thermalito Power Canal. The Thermalito Diversion Dam Power Plant is a 3-MW power plant located on the left abutment of the Diversion Dam. The power plant releases a maximum of 615 cubic feet per second (cfs) of water into the river.

The Power Canal is a 10,000-foot-long channel designed to convey generating flows of 16,900 cfs to the Thermalito Forebay and pump-back flows to the Hyatt Pumping-Generating Plant. The Thermalito Forebay is an off-stream regulating reservoir for the 114-MW Thermalito Pumping-Generating Plant. The Thermalito Pumping-Generating Plant is designed to operate in tandem with the Hyatt Pumping-Generating Plant and has generating and pump-back flow capacities of 17,400 cfs and 9,120 cfs, respectively. When in generating mode, the Thermalito Pumping-Generating Plant discharges into the Thermalito Afterbay, which is contained by a 42,000-foot-long earth-fill dam. The Afterbay is used to release water into the Feather River downstream of the Oroville Facilities, helps regulate the power system, provides storage for pump-back operations, and provides recreational opportunities. Several local irrigation districts receive water from the Afterbay.

The Feather River Fish Barrier Dam is downstream of the Thermalito Diversion Dam and immediately upstream of the Feather River Fish Hatchery. The flow over the dam maintains fish habitat in the low-flow channel of the Feather River between the dam and the Afterbay outlet, and provides attraction flow for the hatchery. The hatchery was intended to compensate for spawning grounds lost to returning salmon and steelhead trout from the construction of Oroville Dam. The hatchery can accommodate an average of 15,000 to 20,000 adult fish annually.

The Oroville Facilities support a wide variety of recreational opportunities. They include: boating (several types), fishing (several types), fully developed and primitive camping (including boat-in and floating sites), picnicking, swimming, horseback riding, hiking, off-road bicycle riding, wildlife watching, hunting, and visitor information sites with cultural and informational displays about the developed facilities and the natural environment. There are major recreation facilities at Loafer Creek, Bidwell Canyon, the Spillway, North and South Thermalito Forebay, and Lime Saddle. Lake Oroville has two full-service marinas, five car-top boat launch ramps, ten floating campsites, and seven dispersed floating toilets. Recreation facilities are also available at the Visitor Center and the OWA.

The OWA comprises approximately 11,000 acres west of Oroville that is managed for wildlife habitat and recreational activities. It includes the Thermalito Afterbay and surrounding lands (approximately 6,000 acres) along with 5,000 acres adjoining the Feather River. The 5,000-acre area straddles 12 miles of the Feather River, which includes willow and cottonwood lined ponds, islands, and channels. Recreation areas include dispersed recreation (hunting, fishing, and bird watching), plus recreation at developed sites, including Monument Hill day use area, model airplane grounds, three boat launches on the Afterbay and two on the river, and two primitive camping areas. California Department of Fish and Game's (DFG) habitat enhancement program includes a wood duck nest-box program and dry land farming for nesting cover and improved wildlife forage. Limited gravel extraction also occurs in a number of locations.

1.3 CURRENT OPERATIONAL CONSTRAINTS

Operation of the Oroville Facilities varies seasonally, weekly and hourly, depending on hydrology and the objectives DWR is trying to meet. Typically, releases to the Feather River are managed to conserve water while meeting a variety of water delivery requirements, including flow, temperature, fisheries, recreation, diversion and water quality. Lake Oroville stores winter and spring runoff for release to the Feather River as necessary for project purposes. Meeting the water supply objectives of the SWP has always been the primary consideration for determining Oroville Facilities operation (within the regulatory constraints specified for flood control, in-stream fisheries, and downstream uses). Power production is scheduled within the boundaries specified by the water operations criteria noted above. Annual operations planning is conducted for multi-year carry over. The current methodology is to retain half of the Lake Oroville storage above a specific level for subsequent years. Currently, that level has been established at 1,000,000 acre-feet (af); however, this does not limit draw down of the reservoir below that level. If hydrology is drier than expected or requirements greater than expected, additional water would be released from Lake Oroville. The operations plan is updated regularly to reflect changes in hydrology and downstream operations. Typically, Lake Oroville is filled to its maximum annual level of up to 900 feet above mean sea level (msl) in June and then can be lowered as necessary to meet downstream requirements, to its minimum level in December or January. During drier years, the lake may be drawn down more and may not fill to the desired levels the following spring. Project operations are directly constrained by downstream operational constraints and flood management criteria as described below.

1.3.1 Downstream Operation

An August 1983 agreement between DWR and DFG titled, *Agreement Concerning the Operation of the Oroville Division of the State Water Project for Management of Fish & Wildlife*, sets criteria and objectives for flow and temperatures in the low flow channel and the reach of the Feather River between Thermalito Afterbay and Verona. This agreement: (1) establishes minimum flows between Thermalito Afterbay Outlet and Verona which vary by water year type; (2) requires flow changes under 2,500 cfs to be reduced by no more than 200 cfs during any 24-hour period, except for flood management, failures, etc.; (3) requires flow stability during the peak of the fall-run Chinook spawning season; and (4) sets an objective of suitable temperature conditions during the fall months for salmon and during the later spring/summer for shad and striped bass.

1.3.1.1 Instream Flow Requirements

The Oroville Facilities are operated to meet minimum flows in the lower Feather River as established by the 1983 agreement (see above). The agreement specifies that Oroville Facilities release a minimum of 600 cfs into the Feather River from the Thermalito Diversion Dam for fisheries purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline.

Generally, the instream flow requirements below Thermalito Afterbay are 1,700 cfs from October through March, and 1,000 cfs from April through September. However, if runoff for the previous April through July period is less than 1,942,000 af (i.e., the 1911-1960 mean unimpaired runoff near Oroville), the minimum flow can be reduced to 1,200 cfs from October to February, and 1,000 cfs for March. A maximum flow of 2,500 cfs is maintained from October 15 through November 30 to prevent spawning in overbank areas that might become de-watered.

1.3.1.2 Water Temperature Requirements

The Diversion Pool provides the water supply for the Feather River Fish Hatchery. The hatchery objectives are 52^{o}F (11.1^{o}C) for September, 51^{o}F (10.6^{o}C) for October and November, 55^{o}F (12.8^{o}C) for December through March, 51^{o}F for April through May 15, 55^{o}F for last half of May, 56^{o}F (13.3^{o}C) for June 1-15, 60^{o}F (15.6^{o}C) for June 16 through August 15, and 58^{o}F (14.4^{o}C) for August 16-31. A temperature range of plus or minus 4^{o}F is allowed for the objectives extending from April through November.

There are several temperature objectives for the Feather River downstream of the Afterbay Outlet. During the fall months, after September 15, the temperatures must be suitable for fall-run Chinook salmon. From May through August, they must be suitable for shad, striped bass, and other warmwater fish.

NOAA Fisheries has also established an explicit criterion for steelhead and spring-run Chinook salmon. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook salmon and steelhead as a reasonable and prudent measure, DWR is required to maintain daily average water temperature of $<$65^{o}F (18.3^{o}C) at Feather River Mile 61.6 (Robinson Riffle in the low flow channel) from June 1 through September 30. The requirement is not intended to preclude pump-back operations at the Oroville Facilities needed to assist the State of California with supplying energy during periods when the California ISO anticipates a Stage 2 or higher alert.

The hatchery and river water temperature objectives sometimes conflict with temperatures desired by agricultural diverters. Under existing agreements, DWR provides water for the Feather River Service Area (FRSA) contractors. The contractors claim a need for warmer water during spring and summer for rice germination and growth (i.e., 65°F from approximately April through mid May, and 59°F (15°C) during the remainder of the growing season). There is no obligation for DWR to meet the rice water temperature goals. However, to the extent practical, DWR does use its operational flexibility to accommodate the FRSA contractor's temperature goals.

1.3.1.3 Water Diversions

Monthly irrigation diversions of up to 190,000 (July 2002) af are made from the Thermalito Complex during the May through August irrigation season. Total annual entitlement of the Butte and Sutter County agricultural users is approximately 1 MAF. After meeting these local demands, flows into the lower Feather River continue into the Sacramento River and into the Sacramento-San Joaquin Delta. In the northwestern portion of the Delta, water is pumped into the North Bay Aqueduct. In the south Delta, water is diverted into Clifton Court Forebay where the water is stored until it is pumped into the California Aqueduct.

1.3.1.4 Water Quality

Flows through the Delta are maintained to meet Bay-Delta water quality standards arising from DWR's water rights permits. These standards are designed to meet several water quality objectives such as salinity, Delta outflow, river flows, and export limits. The purpose of these objectives is to attain the highest water quality, which is reasonable, considering all demands being made on the Bay-Delta waters. In particular, they protect a wide range of fish and wildlife including Chinook salmon, Delta smelt, striped bass, and the habitat of estuarine-dependent species.

1.3.2 Flood Management

The Oroville Facilities are an integral component of the flood management system for the Sacramento Valley. During the wintertime, the Oroville Facilities are operated under flood control requirements specified by the U.S. Army Corps of Engineers (USACE). Under these requirements, Lake Oroville is operated to maintain up to 750,000 af of storage space to allow for the capture of significant inflows. Flood control releases are based on the release schedule in the flood control diagram or the emergency spillway release diagram prepared by the USACE, whichever requires the greater release. Decisions regarding such releases are made in consultation with the USACE.

The flood control requirements are designed for multiple use of reservoir space. During times when flood management space is not required to accomplish flood management objectives, the reservoir space can be used for storing water. From October through March, the maximum allowable storage limit (point at which specific flood release would have to be made) varies from about 2.8 to 3.2 MAF to ensure adequate space in Lake Oroville to handle flood flows. The actual encroachment demarcation is based on a wetness index, computed from accumulated basin precipitation. This allows higher levels in the reservoir when the prevailing hydrology is dry while maintaining adequate flood protection. When the wetness index is high in the basin (i.e., wetness in the watershed above Lake Oroville), the flood management space required is at its greatest amount to provide the necessary flood protection. From April through June, the maximum allowable storage limit is increased as the flooding potential decreases, which allows capture of the higher spring flows for use later in the year. During September, the maximum allowable storage decreases again to prepare for the next flood season. During flood events, actual storage may encroach into the flood reservation zone to prevent or minimize downstream flooding along the Feather River.

2.0 NEED FOR STUDY

Task 2A is a subtask of SP-F10, *Evaluation of Project Effects on Salmonids and Their Habitat in the Feather River Below the Fish Barrier Dam*. Task 2A fulfills a portion of the FERC application requirements by evaluating spawning and incubation substrate suitability for salmonids in the lower Feather River. In addition to fulfilling statutory requirements, information collected during this task may be used in developing or evaluating Resource Actions.

Performing this study is necessary, in part, because operation of the Oroville Facilities affect the suitability of salmonid spawning and incubation substrates in the lower Feather River. Project operations in the lower Feather River may influence the size structure of available gravels, alter gravel recruitment rates, and affect intragravel water temperature and dissolved oxygen concentration. Changes to these habitat components could potentially influence the spawning and embryo incubation life stage of salmonids. Section 5.51(f)(3) of 18 CFR requires reporting of certain types of information in the FERC application for license of major hydropower projects, including a discussion of the fish, wildlife, and botanical resources near the project. The discussion should identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact for ongoing and future operations.

Task 2 of SP-F10 evaluates project effects on the spawning, incubation, and initial rearing period of salmonids in the Feather River. Task 2A of SP-F10, herein, evaluates the suitability of Chinook salmon and steelhead spawning and embryo incubation gravels in the lower Feather River. Task 2B evaluates the effects from the Oroville Facilities operational procedures to spawning Chinook salmon, Task 2C evaluates the timing, magnitude and frequency of water temperatures and their effects on the distribution of salmonid spawning, and Task 2D evaluates the effects of flow fluctuations on redd dewatering. For further description of Tasks 2A, 2B, 2C, and 2D see SP-F10 and associated interim and final reports.

2.1 BACKGROUND INFORMATION

Salmonids have many different life stages, and in general, the physical and biological habitat requirements differ between life stages. Therefore, life stages must be explicitly defined prior to discussing habitat requirements. General life histories for Chinook salmon and steelhead are summarized below, including the definition of the spawning and embryo incubation life stage, followed by discussions concerning water temperatures, dissolved oxygen concentrations, and gravel substrates.

2.1.1 Life Histories of Chinook Salmon and Steelhead

2.1.1.1 Chinook Salmon

In California, Chinook salmon are found in larger lotic systems from the Oregon border south to the Sacramento-San Joaquin system. The Sacramento-San Joaquin system is the southernmost range for this species in the Pacific Northwest (Moyle 2002). DFG has planted Chinook salmon in several reservoirs in California, however natural reproduction in landlocked waterways has yet to be documented (Moyle 2002). The life history strategy of Chinook salmon typically is divided into two categories, stream-type and ocean-type. Across the range of Chinook salmon, there is variation within each of these broad categories that gives rise to stocks or runs. Spring-run Chinook salmon generally exhibit a stream-type life history. Adult spring-run Chinook salmon reportedly enter their natal tributaries as sexually immature fish and hold in the river over the summer while gonadal maturation takes place (DFG 1998a; DWR and USBR 2000; Moyle 2002). Historically, spring-run Chinook salmon were reported to have ascended to the very highest streams and headwaters in the lower Feather River watershed (DFG 1998a). The Fish Barrier Dam below Oroville Dam now restricts fish passage to historic spawning grounds at higher elevations (DFG 1998a). Adult spring-run Chinook salmon reportedly enter the lower Feather River from March through June (Sommer et al. 2001), and spawn from August through October (DFG 1998a; DWR and USBR 2000; Moyle 2002). Currently, any Chinook salmon that spawns from mid-August through early October is considered part of the spring-run by DFG (Nobriga and Buffaloe 2000). At the Feather River Hatchery, all adults entering the hatchery between early September 8 and October 1 are classified as spring-run Chinook salmon (DFG 1998a). Juvenile stream-type salmon tend to rear in fresh water for longer periods of time (>1 year) prior to entering saltwater (Moyle 2002). Adult fall-run Chinook salmon, considered ocean-type, reportedly enter the lower Feather River in late summer and fall, and typically spawn shortly after arriving on the spawning grounds in late September through December (Sommer et al. 2001; Yoshiyama et al. 1998). Fall-run stocks historically have spawned in lowland reaches of larger rivers and tributaries (Yoshiyama 1998). Juvenile ocean-type Chinook salmon tend to rear in fresh water for shorter periods of time (0-12 months) prior to entering saltwater (Moyle 2002). Both spring-run and fall-run juvenile Chinook salmon reportedly emigrate in the lower Feather River as fry shortly after emergence (DWR 2002).

Upon reaching spawning areas, adult female Chinook salmon excavate shallow oval shaped depressions in appropriate gravel beds. The depressions, or nests, are known as redds. The general belief is that each female Chinook salmon constructs multiple redds, but observational data suggest one redd per female is most typical (Crisp and Carling 1989; Neilson and Banford 1983). Spawning occurs over a course of several days during which the female deposits up to four or five groups, or pockets, of eggs into the redd and then covers them with gravel (Healey 1991). After spawning, and prior to dying, female Chinook salmon reportedly spend up to 25 days defending their redd

(Healey 1991). The amount of time between fertilization and emergence varies temporally and spatially, and is heavily dependant on water temperature (Moyle 2002). After incubation, embryos hatch to live as alevins (sac-fry) within interstitial spaces of gravel substrates. The length of time alevins reside in gravel substrates varies, but usually lasts until the yolk sac is fully absorbed (Moyle 2002). Young Chinook salmon are called fry upon emergence from gravel beds. During the transition from fry to parr, juvenile salmonids grow in size and spend more time utilizing deeper and higher velocity habitats for feeding and rearing (Moyle 2002). Juvenile Chinook salmon spend from several months to over a year rearing in freshwater prior to emigrating to saltwater. During emigration, the parr-smolt transformation takes place, which involves morphological, physiological, and behavioral changes designed to increase saltwater survivability. In general, these changes occur gradually while juvenile salmonids are en-route from natal streams to the ocean. Chinook salmon spend between one and four years, but sometimes longer, in the ocean before returning to natal streams to spawn (Myers et al. 1998).

Chinook salmon have many different life stages, and in general, the physical and biological habitat requirements differ between life stages. Therefore, life stages must be explicitly defined prior to discussing habitat requirements. The spawning cycle of Chinook salmon consists of multiple stages. The stages include adult migration and holding, spawning site selection, redd construction, egg and alevin incubation, and residence time on redds. Response to and the effects from physical habitat components vary between these stages. For purposes of this evaluation, spawning and embryo incubation are evaluated together because little literature definitively separates these two life stages. The spawning and embryo incubation life stage is defined as the period from spawning site selection through embryo incubation. An embryo is collectively defined as both egg and alevin. The embryo incubation period extends from egg deposition until juveniles emerge from substrates as free-swimming fry.

2.1.1.2 Steelhead

Steelhead and rainbow trout are genetically identical. Steelhead are considered to be the anadromous form of rainbow trout. In California, steelhead populations are present in coastal streams and rivers from the Smith River near the Oregon border south to Malibu Creek in southern California. Malibu Creek is the known southern extent of persistent steelhead populations in North America, although systems south of Malibu Creek appear to support at least occasional spawning populations (McEwan 2001). The life history of steelhead closely parallels that of salmon, including having multiple distinct runs. In California there are well defined winter-, spring-, and fall-run populations (McEwan 2001). Each run has adopted a particular life history strategy. Stream-maturing steelhead enter fresh water in spring, summer, and early fall, and ascend to headwater pools where they sexually mature prior to spawning in the following winter and spring months. Stream-maturing steelhead are also referred to as summer steelhead and include spring-run populations. Ocean-maturing steelhead enter fresh water in fall, winter and spring, and spawn from January through early summer with the peak spawning occurring from January through March (McEwan 2001; Moyle 2002). Ocean-maturing steelhead are also referred to as winter steelhead and include fall-run and winter-run populations. Winter steelhead range throughout coastal California, while summer steelhead are restricted to Northcoast drainages, particularly the Eel, Klamath, and Trinity river systems (McEwan 2001). Winter steelhead account for the greatest percentage of populations within the Central Valley system, however, summer steelhead likely were more common prior to disturbance activities such as dam construction (Moyle 2002). Steelhead typically rear in fresh water from one to three years prior to saltwater entry, and remain at sea generally from one to four growing seasons prior to returning to natal streams to spawn (McEwan 2001; Moyle 2002). Unlike salmon, steelhead are both semelparous and iteroparous , however, percentages of repeat spawners is uncertain and likely highly variable within and between populations. According to Moyle (2002), surviving spawning and returning to the ocean is primarily a characteristic of winter steelhead. Surviving spawners return to salt water between April and June (USFWS 1995). Half-pounders are a life stage variant found in certain populations and described as immature fish measuring 25-35 cm FL that over winter in freshwater after spending a summer in the ocean (Moyle 2002). The spawning cycle of steelhead is identical to salmon with adults excavating redds, depositing eggs, and embryos incubating within gravels prior to emergence as fry. The parr-smolt transformation takes place during emigration and involves morphological, physiological, and behavioral changes designed to increase saltwater survivability. In general, these changes occur gradually while juvenile steelhead are en-route from natal streams to the ocean. Available literature suggests that steelhead are more sensitive to elevated water temperatures, throughout their range and during each life stage, than are salmon, and generally require lower water temperatures for normal physiological and behavioral responses.

Steelhead have many different life stages, and in general, the physical and biological habitat requirements differ between life stages. Therefore, life stages must be explicitly defined prior to discussing habitat requirements. The spawning cycle of steelhead consists of multiple stages including adult migration and holding, spawning site selection, redd construction, egg and alevin incubation, and residence time on redds. Response to and the effects from physical habitat components vary between these stages. For purposes of this evaluation, spawning and embryo incubation are evaluated together because available literature rarely definitively separates these two stages. The spawning and embryo incubation life stage is defined as the period from spawning site selection through embryo incubation. An embryo is collectively defined as both egg and alevin. Steelhead spawning includes the time period from spawning site selection through egg fertilization. The embryo incubation period extends from egg deposition until juveniles emerge from substrates as free-swimming fry. In the Central Valley, steelhead spawning reportedly occurs from October through June (McEwan 2001), with embryo incubation lasting roughly 2 to 3 months after deposition (McEwan 2001; Moyle 2002; Myrick and Cech Jr. 2001). In the Feather River, steelhead spawning and embryo incubation extends from December through May, with peak spawning occurring in January and February (pers. comm., Cavallo 2004 ; McEwan 2001; Moyle 2002).

2.1.2 Water Temperatures

In the past century, anadromous salmonid populations in the Central Valley of California have experienced reductions in size and range, in some cases to extinction (Myrick and Cech Jr. 2001). Because salmon are poikilothermic, water temperature is a highly influential physical factor for all life stages. Many of the rivers and tributaries in the Sacramento-San Joaquin River system contain impoundments and diversions. As a result, the system is highly regulated and monitored by regulatory agencies such as USBR, USFWS, and NOAA Fisheries. Typically, water diversion and water use projects affect in-river water temperatures by altering flow regimes. Legislation and agreements between stakeholders mandate provision of various water temperature ranges to accommodate salmonids. Development and appropriate application of technical evaluation guidelines is necessary when assessing project impacts, evaluating if project activities are in compliance with existing legislation, and when assessing the suitability of water temperatures. Salmonids have many different life stages, and in general, differences exist between the thermal requirements of each life stage. Therefore, salmonid life stages must be explicitly defined prior to selecting the appropriate water temperature index values to be used as guidelines for impact assessments. A broad understanding of responses to water temperature regimes is necessary in order to successfully evaluate the suitability of water temperature regimes to a given salmonid life stage or the entire life cycle. A literature review was conducted to: (1) interpret the literature on temperature effects to Chinook salmon and steelhead during each life stage, (2) consider the effects of short-term and long-term exposure to constant or fluctuating water temperatures, (3) establish biologically defensible water temperature index values to be used as guidelines for impact and suitability assessments.

The lower Feather River is near the southern extent of the geographic range of Chinook salmon and steelhead. Thus, Chinook salmon and steelhead in the lower Feather River likely evolved in environments having higher ambient water temperatures when compared to other Pacific Northwest salmonid populations. Water temperatures during the Chinook salmon and steelhead spawning and embryo incubation life stage in the lower Feather River may be near the upper range of reported thermal tolerances for these species. Ambient air temperatures in the Central Valley remain relatively mild throughout the year, and the effects from elevated water temperatures are the primary concern. Water temperatures in the lower Feather River rarely drop below 45^{o}F (7.2^{o}C) (DWR 2003b). Based on results reported in available literature, 45^{o}F (7.2^{o}C) likely would not result in adverse effects to the spawning and embryo incubation life stage. Therefore, this report will only address the effects to the spawning and embryo incubation life stage of Chinook salmon and steelhead from elevated water temperatures.

Selection of water temperature index values to use as criteria for impact and suitability assessments to the spawning and embryo incubation life stage of Chinook salmon and steelhead is difficult because a wide range of values, often contradictory, are recommended in available literature. The water temperature index values selected as criteria in this report were chosen from values reported and recommended in regulatory agency documents and from source data, usually peer reviewed journal articles. Values found in the documents of regulatory agencies are important because they have legal ramifications, and water use projects typically are mandated to operate within the thermal criteria provided in these documents.

Water temperature values reported for the spawning and embryo incubation life stage of Chinook salmon and steelhead, in many instances, are the results of direct observations of spawning fish. The reported values do not necessarily reflect preferred or optimal water temperatures, but simply those water temperatures at which spawning was observed. Conditions responsible for maximizing the number of adults spawning, the number of eggs deposited, and the number of eggs and alevins surviving is likely a complex synergistic interaction of multiple variables. The specialized life history of salmonids restricts flexibility in the duration and timing of the spawning cycle. Spawning salmonids are temporally constrained, and regardless of whether conditions are conducive to spawning, they will eventually spawn. For example, during unseasonably warm years, salmon may spawn well outside of reported preferred, optimal, or suitable water temperature ranges. Therefore, caution should be used in the interpretation and application of water temperature index values derived from observations of spawning Chinook salmon and steelhead. The water temperature index values defined and used as criteria for impact assessments in this report also outline guidelines that are used for consideration in making resource management decisions.

2.1.2.1 Water Temperatures and the Spawning and Embryo Incubation Life Stage of Chinook Salmon

In the Sacramento River basin, Chinook salmon spawning reportedly occurs from early January to April for the late fall-run, from late April to early August for the winter-run, from late August to October for the spring-run, and from late September to December for the fall-run (Fisher 1994). In the lower Feather River, adult spawning and embryo incubation reportedly occurs from mid-August (based on observations of carcasses on September 1 through mid-February DWR 2004a). The duration of embryo incubation is dependent on water temperature and can be variable (NOAA Fisheries 2002a). In Butte and Big Chico creeks, emergence of spring-run Chinook salmon generally occurs from November through January (NOAA Fisheries 2002). In Mill and Deer creeks, colder water temperatures delay emergence to January through March (DFG 1998a). In the lower American River, fall-run Chinook salmon emergence generally begins in March (SWRI 2004).

The adult spawning and embryo (eggs and alevins) incubation life stage includes the time period from redd construction through embryo incubation. However, this report will focus on the thermal suitability of the intragravel environment to incubating embryos.

Many of the water temperature values mentioned in the available literature for the Chinook salmon spawning and embryo incubation life stage are supported by anecdotal evidence, and values derived from experimental testing are limited. In general, there are three types of literature that provide information on criteria used for impact assessments and resource management decisions: (1) research results typically published in peer reviewed journals, (2) literature reviews citing various types of documents, and (3) agency publications that often contain legal mandates. Many of the water temperature values currently used as technical evaluation guidelines for resource management decisions were established decades ago through controlled experiments and observations. Chambers (1956) described spawning site characteristics for 27 streams in Washington, Idaho, and Oregon. Spring-run Chinook salmon reportedly were observed spawning at water temperatures between 40°F (4.4°C) and 55°F (12.8°C) with an average daily water temperature of 54°F (12.2°C). Fall-run Chinook salmon were observed spawning at water temperatures between 41°F (5°C) and 56°F (13.3°C) with an average daily water temperature of 50°F (10°C). Chambers (1956) also reported that declining water temperatures appeared to act as a cue initiating the spawning cycle. Seymour (1956) reported that the shortest hatching period occurred in egg lots reared between 40°F (4.4°C) and 58°F (14.4°C), and that short hatching periods are associated with high survival. Other relevant conclusions from this study were that 100 percent mortality occurred during the yolk-sac stage in egg lots reared at 60°F (15.6°C) and 62.5°F (16.9°C), and the mortality rate was low at all stages of development for lots reared at water temperatures between 40°F (4.4°C) and 55°F (12.8°C). In an annual report concerning the productivity of the Nimbus Fish Hatchery on the American River, Hinze (1959) reported basic observations on the correlation between water temperature and incubating eggs. The report states there was 100 percent mortality of eggs incubated in water above 62°F (16.7°C), a yield of 50 percent to the eyed stage when eggs were incubated in water between 60°F (15.6°C) and 62°F (16.7°C), and a yield of 80 percent to the eyed stage when eggs incubated in water between 55°F (12.8°C) and 59°F (15°C). Hinze (1959) is frequently cited in literature reviews and agency publications. The observations from this report should be interpreted carefully and applied with caution because the values were derived from basic observations lacking rigorous testing and replication on very small sample sizes. Combs and Burrows (1957) tested the effect of constant incubating water temperatures on the development of Chinook salmon eggs. The study concluded that egg incubation temperatures between 42.5°F (5.8°C) and 57.5°F (14.2°C) provided for normal development, but that results applied only to eggs incubated at constant water temperatures. Dauble and Watson (1997) monitored spawning Chinook salmon in the Hanford Reach of the mid-Columbia River from 1948 through 1992. Fall-run Chinook salmon reportedly spawned at mean daily water temperatures ranging from 53.6°F (12°C) to 65.3°F (18.5°C). Mean weekly water temperature at first observed spawning was 59.5°F (15.3°C) from 1948 to 1988. Approximately 75 percent of the spawning was initiated when weekly mean temperatures dropped to between 60.8°F (16°C) and 57.2°F (14°C). During peak spawning, the mean weekly water temperature was 54.5°F (12.5°C) and the maximum weekly water temperature was 57.2°F (14°C). Groves and Chandler (1999) described spawning habitat used by fall-run Chinook salmon in the Snake River. The overall distribution of mean weekly water temperatures obtained from 151 redds during 1993-1995 reportedly ranged from 41°F (5°C) to 60.6°F (15.9°C), and averaged 50.9°F (10.5°C). Water temperatures averaged 56.5°F (13.6°C) during the week of spawning initiation, and 45.5°F (7.5°C) during the week that spawning activities concluded.

Many literature reviews have summarized the thermal tolerances for the spawning and embryo incubation life stage of Chinook salmon, and many of these reviews are commonly cited in the literature. Chinook salmon have been observed spawning throughout a wide range of water temperatures (Raleigh et al. 1986), due in part to clinal variation in climatic conditions across their geographical range. A literature review by Bjornn and Reiser (1991) concluded that, based on Bell (1986), water temperatures between 42.1°F (5.6°C) and 57°F (13.9°C) are recommended for the spawning and embryo incubation life stage of Chinook salmon. Bell (1991) reviewed available literature and determined that the general water temperature range for spawning Chinook salmon was between 42°F (5.6°C) and 57.5°F (14.2°C), with 51.8°F (11°C) as the preferred spawning water temperature. However, it is difficult to have confidence in the values listed in Bell (1991) because of a typographical error (pg. 11.3), which also was present in Bell (1986) (pg. 95), and because it is difficult to determine the source data the water temperature values were based on. Boles et al. (1988) relied heavily on the results from Seymour (1956) to conclude that eggs incubated at constant water temperatures greater than 60°F (15.6°C) suffer high mortalities. McCullough (1999) concluded that 42°F (5.6°C) to 55°F (12.8°C) appeared to be a reasonable recommendation for a water temperature range for spawning Chinook salmon in the Columbia River Basin because alevin development, linked to thermal exposure of eggs in ripe females or newly deposited in gravels, and egg maturation are negatively affected by exposure to water temperatures above approximately 54.5°F (12.5°C) to 57.2°F (14°C). The literature review also stated that it could be assumed that spawning will not occur at water temperatures greater than approximately 60.8°F (16°C).

Documents from regulatory agencies, such as biological assessments and biological opinions, offer additional literature from which water temperature values can be derived. Spawning water temperatures of 55°F (12.8°C) have typically been recommended for Chinook salmon because studies of egg survival and development indicate reduced survival under water temperatures between 53.6°F (12°C) to 60.8°F (16°C) (EPA et al. 1971). In the Sacramento River from Keswick Dam to Bend Bridge, NOAA Fisheries (1993) determined that, during October, a water temperature of 60°F (15.6°C) was appropriate for protecting late incubating larvae and newly emerged fry, and that the optimum water temperature for egg development was between 43°F (6.1°C) and 56°F

(13.3°C). NOAA Fisheries (1997) reported that the preferred water temperature for Chinook salmon incubation is generally 52°F (11.1°C) with lower and upper threshold water temperatures of 42°F (5.6°C) and 56°F (13.3°C), and that reduced egg viability and significant egg mortality occurs at water temperatures in excess of 57.5°F (14.2°C). NOAA Fisheries (2002) partially agreed with these values by reporting that the range of suitable water temperatures for incubation through emergence is 48°F (8.9°C) to 52°F (11.1°C), the upper limit of suitable water temperature for spawning is 56°F (13.3°C), and the preferred water temperatures for eggs and fry are 53°F (11.7°C) to 58°F (14.4°C). NOAA Fisheries (2002) is an excellent example of the difficulties associated with interpreting thermal tolerance literature. For example, it is unclear what the differences are between some of the mentioned life stages, such as incubating and eggs, which reinforces the importance of explicitly defining life stages. USFWS (1995) determined that maximum survival of eggs and yolk-sac larvae occurs at water temperatures between 41°F (13.3°C) and 56°F (13.3°C), and that mature female Chinook salmon subjected to prolonged exposure to water temperatures above 60°F (15.6°C) have poor survival rates and produce less viable eggs than females exposed to lower water temperatures. USFWS (1999) studied the effect of temperature on early-life survival of Sacramento River Chinook salmon and concluded that incubation temperatures above 56°F (13.3°C) result in significantly higher alevin mortality, and that incubation temperatures of 62°F (16.7°C) to 64°F (17.8°C) appeared to be the physiological limit for embryo development resulting in 80 percent to 100 percent mortality prior to emergence. The Oregon Department of Environmental Quality (ODEQ 1995) conducted a literature review and recommended a spawning water temperature range of 42°F (5.6°C) to 55°F (12.8°C) for Chinook salmon because the exposure of newly deposited eggs to intragravel water temperatures above approximately 55°F (12.8°C) increases egg mortality, and inhibits subsequent alevin development. A summary of technical literature by EPA (2001) concluded that a suitable water temperature range of 42°F (5.6°C) to 55°F (12.8°C) appeared to be a reasonable recommendation for spawning Pacific salmon. In a separate report, EPA (2001) quoted the Independent Scientific Group (1996) as stating that the optimal temperature for anadromous salmonid spawning is 50°F (10°C), and that stressful conditions for anadromous salmonids begin at a water temperature of 60.1°F (15.6°C) with lethal effects occurring at 69.8°F (21°C). The *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* (Palmer 2003) discusses criteria and describes an approach that EPA Region 10 encourages states and authorized tribes in the Pacific Northwest to use when adopting water temperature standards to protect coldwater salmonids. The criteria were developed by a multi-agency panel through a review and summary of the latest literature related to water temperature and salmonids. Based on the criteria developed by the panel, Palmer (2003) suggested that the seven-day average of the daily maximum water temperatures should not exceed 55.4°F (13°C) during the period when Chinook salmon are spawning and eggs are incubating.

In general, the process of establishing water temperature criteria involves subjectivity. The use of models may limit subjectivity by standardizing the decision making process. The salmon mortality model, developed by USBR, is a tool frequently used to predict salmon mortality, based on many variables, in rivers in the Central Valley, including the Feather and American rivers (USBR Unpublished Work). The model specifies that water temperatures less than 56°F (13.3°C) result in a natural rate of mortality for fertilized Chinook salmon eggs, 100 percent mortality of fertilized eggs occurs after 12 days at 62°F (16.7°C), 100 percent mortality of fertilized eggs occurs after 7 days at 64°F (17.8°C), and 100 percent mortality of alevins occurs after 10 days at 64°F (17.8°C).

A review of available literature regarding the thermal effects to the spawning and embryo incubation life stage of Chinook salmon found many different water temperature values, and using all of the values as evaluation criteria is not efficient or reasonable. In certain instances, chosen values were rounded up or down but were still very similar to, and representative of, cited water temperature values. The water temperature index values selected in this report as criteria for impact assessments were chosen because they represent the values most commonly recommended by primary sources and regulatory agencies, and because the range of selected values encompass the range of values most often referenced in available literature. For purposes of this report, 56°F (13.3°C), 58°F (14.4°C), 60°F (15.6°C), and 62°F (16.7°C) were used as technical evaluation guidelines to assess the potential thermal impacts from operation of the Oroville Facilities to the Chinook salmon spawning and embryo incubation life stage in the lower Feather River.

2.1.2.2 Water Temperatures and the Steelhead Spawning and Embryo Incubation Life Stage

Steelhead spawning includes the time period from redd construction through egg deposition. The embryo (eggs and alevins) incubation period extends from deposition until the juveniles emerge from gravel substrates as free-swimming fry. In the Central Valley, steelhead spawning reportedly occurs from October through June (McEwan 2001), and embryo incubation generally lasts 2 to 3 months after deposition (McEwan 2001; Moyle 2002; Myrick and Cech Jr. 2001). Like Chinook salmon, the steelhead embryo life stage is the most vulnerable to elevated water temperatures. Because the initial embryo incubation water temperatures are a function of spawning water temperatures, one set of water temperature index values was established to evaluate spawning adults and incubating embryos. However, this report will focus on the thermal suitability of the intragravel environment to incubating of embryos.

Few studies have been published regarding the effects of water temperature on steelhead spawning and embryo incubation (Redding and Schreck 1979; Rombough 1988). Studies on non-anadromous rainbow trout were considered in the development of water temperature index values for steelhead spawning and embryo incubation

(McEwan 2001; Moyle 2002) because anadromous steelhead and non-anadromous rainbow trout are genetically identical. Based on available literature, water temperatures in the low 50°F (10°C) range appear to support high embryo survival with substantial mortality to steelhead eggs reported at water temperatures in the high 50°F (10°C) range and above. Water temperature index values of 52°F (11.1°C), 54°F (12.2°C), 57°F (13.9°C), and 60°F (15.6°C) were selected as indicators of habitat suitability for two reasons. First, available literature provided the strongest support for water temperature index values at or near 52°F(11.1°C), 54°F (12.2°C), 57°F (13.9°C), and 60°F (15.6°C). Second, the index values reflect an evenly distributed range representing optimal to lethal conditions for steelhead spawning and embryo incubation. Although some literature suggests water temperatures ≤50°F (10°C) are optimal for steelhead spawning and embryo survival (Myrick and Cech Jr. 2001; Timoshina 1972), a larger body of literature suggests optimal conditions occur at water temperatures ≤52°F (Humpesch 1985; NOAA Fisheries 2000; NOAA Fisheries 2001; NOAA Fisheries 2002a; State Water Resources Control Board 2003; USBR 1997; USFWS 1995). Therefore, 52°F (11.1°C) was selected as the lowest water temperature index value. Although most of the studies conducted at or near 54°F (12.2°C) reported high survival and normal development (Kamler and Kato 1983; Redding and Schreck 1979; Rombough 1988), some evidence suggests that symptoms of thermal stress arise at or near 54°F (12.2°C) (Humpesch 1985; Timoshina 1972). Thus, water temperatures near 54°F (12.2°C) may represent an inflection point between suitable water temperature conditions and conditions that cause negative effects to steelhead spawning and embryo incubation. Embryonic mortality reportedly increases sharply, and development becomes retarded, at incubation temperatures greater than or equal to 57°F (13.9°C). Velsen (1987) provided a compilation of data on rainbow trout and steelhead embryo mortality to 50 percent hatching under incubation temperatures ranging from 33.8°F (1°C) to 60.8°F (16°C) that demonstrated a 2-fold increase in mortality for embryos incubated at 57.2°F (14°C) compared to embryos incubated at 53.6°F (12°C). In a laboratory study using gametes from Big Qualicum River, Vancouver Island, steelhead mortality increased to 15 percent at a constant water temperature of 59°F (15°C) compared to less than 4 percent mortality at constant water temperatures of 42.8°F (6°C), 48.2°F (9°C), and 53.6°F (12°C) (Rombough 1988). Also, alevins hatching at 59°F (15°C) were considerably smaller and appeared less well developed than those incubated at the lower water temperature treatments. From fertilization to 50 percent hatching, Big Qualicum River steelhead had 93 percent mortality at 60.8°F (16°C), 7.7 percent mortality at 57.2°F (14°C), and 1 percent mortality at 47.3°F (8.5°C) and 39.2°F (4°C) (Velsen 1987). Based on Velsen (1987) and Rombough (1988), 57°F (13.9°C) and 60°F (15.6°C) were chosen as water temperature index values.

3.0 STUDY OBJECTIVES

The objective of SP-F10 Task 2A is to evaluate the suitability of Chinook salmon and steelhead spawning and embryo incubation substrates in the lower Feather River, to describe the current size structure of available substrates, and document temporal changes in size structure and recruitment of substrates.

3.1 APPLICATION OF STUDY INFORMATION

The purpose of SP-F10 Task 2A is to assist the FERC relicensing process and to fulfill statutory requirements. Information collected during this task may be used in developing or evaluating potential Resource Actions. Additionally, information obtained in this study is associated with, and will be applied to, the following purposes and activities.

3.1.1 Department of Water Resources/Stakeholders

The information from Task 2A of SP-F10 will be used by DWR and the Environmental Work Group (EWG) to evaluate the suitability of spawning substrates in the lower Feather River. Additionally, data collected in this task serve as a foundation for future evaluations and development of potential Resource Actions.

3.1.2 Other Studies

As a subtask of study plan SP-F10, *Evaluation of Project Effects on Salmonids and Their Habitat in the Feather River Below the Fish Barrier Dam*, Task 2 evaluates project effects on the spawning, incubation, and initial rearing period of salmonids in the Feather River. Task 2A of SP-F10, herein, evaluates the suitability of Chinook salmon and steelhead spawning and embryo incubation gravels in the lower Feather River. Task 2B evaluates the effects from the Oroville Facilities operational procedures to spawning Chinook salmon, Task 2C evaluates the timing, magnitude and frequency of water temperatures and their effects on the distribution of salmonid spawning, and Task 2D evaluates flow fluctuation-related effects on redd dewatering. and on egg and alevin survival. For further description of Tasks 2A, 2B, 2C, and 2D see SP-F10 and associated interim and final reports.

3.1.3 Environmental Documentation

In addition to Section 4.51(f)(3) of 18 CFR, which requires reporting of certain types of information in the FERC application for license of major hydropower projects, it may be necessary to satisfy the requirements of the National Environmental Policy Act (NEPA) and the ESA. Because FERC has the authority to grant an operating license to DWR for continued operation of the Oroville Facilities, discussion is required to identify the potential impacts of the project on many types of resources, including fish, wildlife, and botanical resources. In addition, NEPA requires discussion of any anticipated continuing impact from on-going and future operations. To satisfy NEPA and the ESA, DWR is preparing a Preliminary Draft Environmental Assessment (PDEA) to attach to the FERC license application, which will include information provided by this study plan report.

3.1.4 Settlement Agreement

In addition to statutory and regulatory requirements, SP-F10 Task 2A could provide information to aid in the development of potential Resource Actions to be negotiated during the collaborative process. Also, information obtained from the evaluation of spawning substrates could be used by the collaborative to negotiate operating procedures.

4.0 METHODOLOGY

The objectives of SP-F10 Task 2A were accomplished by collecting intragravel and bulk gravel data in the lower Feather River. The main objectives of the intragravel sampling were to determine permeability, dissolved oxygen concentration, water temperature, and the upwelling and downwelling potential within streambed substrates. The main objective of the bulk gravel sampling was to determine the size structure distribution of available gravel substrates. The methodologies for each sampling type are summarized below including associated analyses.

4.1 INTRAGRAVEL SAMPLING

Intragravel sampling was conducted in the lower Feather River from August 6, 2003 through November 13, 2003. Permeability, dissolved oxygen concentration, water temperature, and upwelling and downwelling potential data were collected within gravel substrates 6 inches, 12 inches, and 18 inches below the substrate surface at each sample site (Figure 4.1-1). Intragravel data were collected concurrently at the same sites within riffles. The definition used for riffle was consistent with the definition of riffle found in DFG (1998).

Intragravel data were recorded at 15 riffles in the lower Feather River. Riffles that were easily accessed and having a high degree of spawning use were chosen as study sites. Ten of the riffles were located in the LFC, and 5 of the riffles were located in the HFC. Multiple site types were sampled in each riffle except Goose Riffle. Site types were defined as dune, trough, top, middle, and bottom. Riffles often displayed alternating high and low bedforms transverse to instream flow. The high region was defined as a dune, and the adjacent low region was defined as a trough. Dune and trough data were collected only in the LFC (Hatchery Riffle and Eye Riffle) at randomly chosen sites outside of areas considered to be disturbed by spawning Chinook salmon (i.e., non-redd sites). Fourteen sample sites were visited at non-redd sites. The site type for 6 of the non-redd sample sites could not be determined, 5 sample sites were characterized as dune, and 3 sample sites were characterized as trough.

For sample sites within Chinook salmon redds, the linear extent of each spawning riffle was determined by visual approximation, and then loosely divided into three segments defined as top, middle, and bottom. The top segment was located farthest upstream. In each segment and in each riffle, data were recorded in front of the tailspill mass within Chinook salmon redds (Figure 4.1-2). In several riffles, data could not be gathered in middle and bottom site types because redds were located in water depths exceeding the limitations of sampling gear. Thirty nine sample sites were visited within Chinook salmon redds. In the LFC, 10 riffles were sampled, which comprised a total of 27 sample sites. The 27 sample sites included 11 top sites, 9 middle sites, and 7 bottom sites. In the HFC, 5 riffles were sampled, which comprised a total of 12 sample sites. The 12 sample sites included 5 top sites, 3 middle sites, and 4 bottom sites.

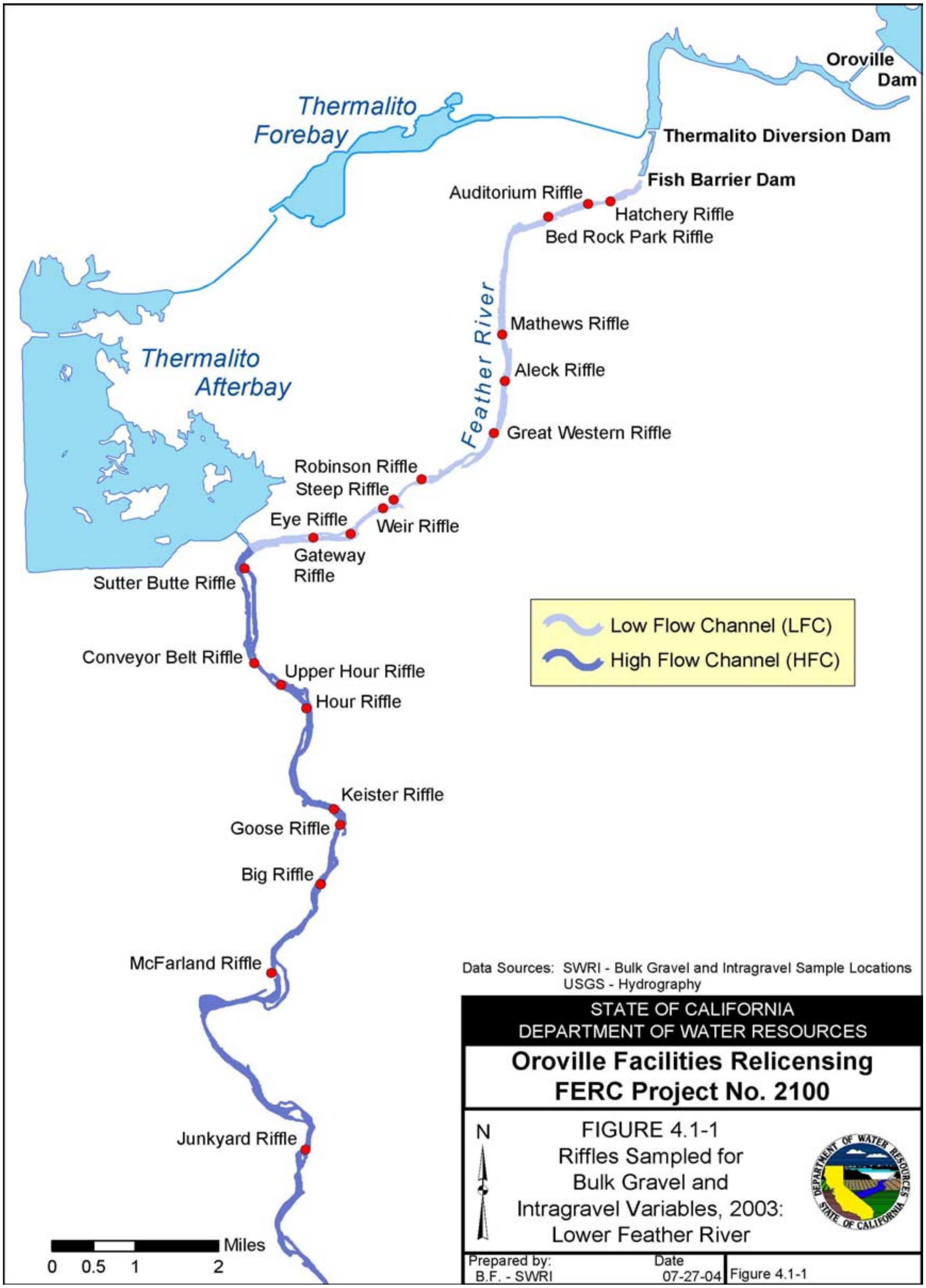

Figure 4.1-1. Riffles sampled for bulk gravel samples and intragravel variables in the lower Feather River.

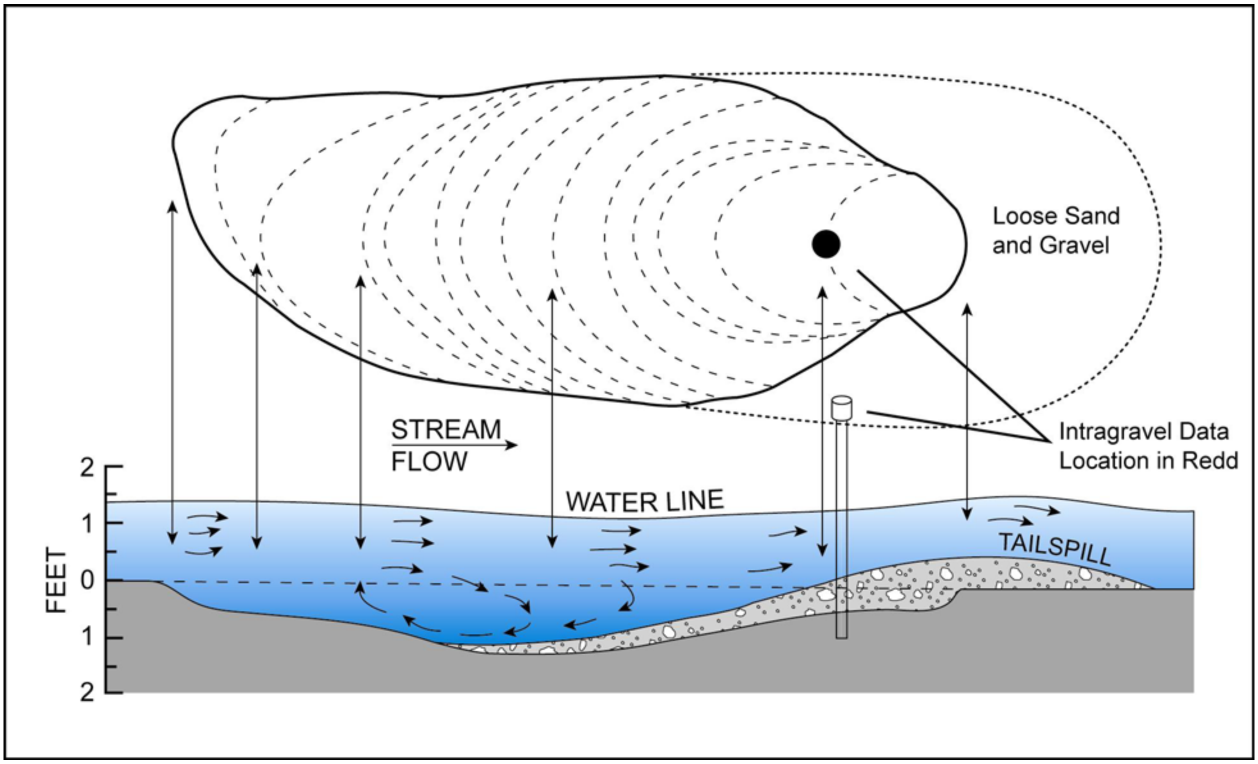

Figure 4.1-2. Location within a Chinook salmon redd that intragravel data were recorded.

4.1.1 Permeability

Permeability data were collected using a Terhune (1958) standpipe modified with an electric pump. The addition of the electric pump eliminated potential user bias associated with hand pumps. A Thomas Inc. (model 107CDC20) electric pump was mounted inside a toolbox, attached externally to a backpack, and connected to a 12-volt battery that was secured inside the backpack. A switch was mounted through the side of the toolbox so the pump could be turned on/off externally. A length of 3/8 inch diameter plastic tubing connected the pump to an overflow bottle and to the top of a vacuum chamber. The vacuum chamber consisted of a clear plastic tube that was 4 inches in diameter, was 30 inches long, and had a 6 liter capacity. A half inch hole was drilled into the bottom of the vacuum chamber, and sealed with an expandable boat plug allowing easy drainage. A length of 3/8 inch diameter plastic tubing was connected externally to the side of the vacuum chamber using brass fittings, and facilitated reading water levels inside of the chamber. An additional length of 3/8 inch diameter plastic tubing was connected on one end to the bottom of the vacuum chamber, and on the other end to a 5 foot piece of 3/8 inch diameter stainless steel tubing. When operating, the vacuum chamber and the backpack were attached to a tripod positioned adjacent to the sample site, and the stainless steel tubing was inserted inside the standpipe to remove water. The standpipe consisted of a 1 3/4 inch diameter steel pipe approximately 4 1/2 feet long. A stainless steel driving point closed one end of the standpipe. The standpipe was perforated with forty-eight evenly spaced 3.2 mm diameter holes located approximately 2 1/2 inches to 4 1/2 inches above the tip of the driving point. The holes were placed along 16 vertical 1.6 mm wide by 1 mm deep grooves in a staggered fashion, which allowed water to flow into the standpipe. The opposite end of the standpipe was fitted with a 2 1/2 inch diameter collar so that a stainless steel driving head could be placed on top of the standpipe when being driven into the gravels with a sledgehammer.

After the standpipe was driven to the appropriate depth within the gravel substrate, the inside of the standpipe was purged of surface water and any sediment that accumulated during the driving process. Purging was necessary because fines that accumulated within the standpipe, as a result of the driving process, could potentially influence the permeability readings. Approximately five liters of water were purged prior to collecting data. Permeability measurements were obtained by pumping water from the standpipe into the vacuum chamber and measuring the time it took to fill a unit volume (1/2 liter or 1 liter). Four to eight replicate measurements of inflow rate were made at each sample site, and at each sample depth. Although the vacuum chamber had a six liter volume, only the middle four liters were calibrated in the vacuum chamber. Thus, the number of replicate measurements for each sample was four or eight, depending on the unit volume being used. The criteria used to determine which unit volume to use per sample was as follows: if it took less than two minutes to fill the vacuum chamber with 1/2 liter of water then 1 liter unit volume was used, if it took greater than two minutes to fill the vacuum chamber with 1/2 liter of water then 1/2 liter unit volume was used. The raw permeability data were converted to cm/hr by multiplying by a viscosity correction factor based on water temperature at the depth being sampled. For each sample site and at each sample depth, replicate measurements of inflow rate were pooled to determine the mean permeability.

4.1.2 Dissolved Oxygen Concentration and Water Temperature

Intragravel dissolved oxygen concentration and water temperature data were collected using a Terhune (1958) standpipe. The standpipe was driven into gravel substrates until the desired depth was reached. A dissolved oxygen and water temperature probe was lowered into the standpipe following the intragravel permeability data collection process. The probe sensor was continually stirred by hand until the dissolved oxygen concentration reading stabilized, which took approximately one minute to ten minutes. Once the readings stabilized, the dissolved oxygen concentration and water temperature were recorded. One dissolved oxygen concentration and one water temperature reading were recorded per sample site and at each sample depth (i.e., 6 inches, 12 inches, and 18 inches).

4.1.2.1 Diel Fluctuation in Dissolved Oxygen Concentration

The time of day that intragravel data were collected was not standardized, and it is possible that dissolved oxygen concentrations fluctuated during each 24 hour period. To determine if diel fluctuations occur in dissolved oxygen concentrations in the lower Feather River, multiple dissolved oxygen concentration readings were taken at various sites in Auditorium Riffle on October 29, 2003. Dissolved oxygen concentration was recorded 18 times from 0535 to 1723. Readings were taken 6 inches to 8 inches within gravels in Chinook salmon redds, and within the water column. Readings within gravels generally were recorded at different times than readings recorded within the water column. Nine dissolved oxygen concentration readings were taken within gravels in Chinook salmon redds, and 9 dissolved oxygen concentration readings were taken within the water column.

4.1.3 Upwelling and Downwelling Potential

The upwelling and downwelling potential at each sample site and each sample depth was determined by first driving the standpipe to the appropriate depth within the gravel substrate. Measurements (cm) were taken of the height of the water column within the standpipe, and the height of the water outside the standpipe from the top of the river bed to the top of the water column. The difference between the two measurements indicated the upwelling and downwelling potential.

4.2 BULK GRAVEL SAMPLING

Bulk gravel samples were collected in the lower Feather River from October 2, 2002 through September 18, 2003. Surface and subsurface gravel size distributions were evaluated at 20 riffles in the lower Feather River. In certain instances, multiple samples were collected at one riffle. A total of 13 samples were collected from 11 riffles in the LFC, and a total of 14 samples were collected from nine riffles in the HFC (Figure 4.1-1).

The bulk gravel sampling involved collecting a large volume of gravel for mechanical analysis by sieving. Sample size was determined by weighing the largest grain within the surface stratum within a randomly chosen 30-inch diameter area. The weight of the largest grain was considered to represent 1 percent of the total sample weight necessary for a statistically representative sample (Bunte and Abt 2001), and total sample weight was site specific. Therefore, total sample weight varied between sample sites. The coarsest grains were assumed to be located in the surface stratum, and when this assumption was not met, sample weights were not adjusted. The depth of surface samples also were determined by the largest grain present in the surface stratum. Therefore, the definition of the surface stratum was site specific, and differed among sample sites. The b-axis of the largest grain present defined the depth of each surface sample. The b-axis is defined as an intermediate length axis, approximately midway in length between the longest and shortest axes. A more detailed description and definition of grain axes can be found in Bunte and Abt (2001). A 30 inch diameter by 22 inch culvert was pushed into gravel substrates to isolate sample gravels from river currents. Gravel was removed from within the culvert using a shovel. Once all gravel was removed from the defined surface layer, subsurface samples were collected until the defined total sample weight was extracted. The subsurface stratum typically extended to a depth of 6 inches to 12 inches beyond the depth of the surface stratum. Therefore, the definition of the subsurface stratum was site specific, and differed among sample sites.

Total sample weight was recorded on site using a digital balance and weighing buckets. Surface and subsurface samples were collected and analyzed separately so that the effects from armoring could be evaluated. Samples were spread onto a tarp, and after drying, were loaded into a series of rocker sieves for size class separation. Gravels representing each size class were weighed and recorded separately. The influence of any moisture remaining on the coarser particles, and all moisture retained in the sample associated with material less than 8 mm in diameter, was assumed to be negligible. Particles finer than 8 mm in diameter were collected in the bottom of each rocker sieve, decanted of any free water, then placed on the tarp to continue drying until weighed. Grains <0.063 mm in diameter were not considered, and were discarded with the drain water.

4.3 DATA ANALYSES

4.3.1 Intragravel Sampling

The study design of the intragravel sampling precluded rigorous statistical comparisons, and analyses generally were limited to descriptive statistics. Box and whisker plots were constructed for visual representation and coarse interpretation of differences among strata. When appropriate, a two sample t-test and a one way Analysis of Variance (ANOVA) were used to test for differences among strata.

4.3.2 Bulk Gravel Sampling

4.3.2.1 Gravel Size Distribution Curves

Gravel size distribution curves offer a visual display of bulk gravel samples, and allow a coarse interpretation of the gravel size distribution between samples. Gravel size distribution curves were constructed for each sample site, separating surface and subsurface samples. Additionally, the gravel size distribution curve for each surface sample was combined in one figure as a means to evaluate distributions between the LFC and HFC. The procedure was repeated for subsurface samples.

A range of suitable gravel size distributions was adopted from Vyverberg et al. (1997), and included in each figure as a general reference to the suitability of each gravel size distribution curve. A detailed explanation and description of the methodology associated with development of the suitability curves is provided in Vyverberg et al. (1997). Re-construction of the suitability curves, for use in this report, was accomplished through visual estimation because the data points used to construct the original suitability curves were not available

4.3.2.2 Median Gravel Diameter (D_{50})

The median gravel diameter (D_{50}) was calculated for each stratum (surface, subsurface) at each study site. Within and among sample site comparisons were made to determine spatial differences in median gravel diameter between surface and subsurface samples. The mean length of female Chinook salmon in the lower Feather River (determined from carcass survey data from 2000 through 2003) was used to calculate the maximum median gravel diameter moveable by Chinook salmon (Kondolf and Wolman 1993) during redd construction. The resulting value was compared to the D_{50} for each riffle to determine if spawning gravels were suitable for redd construction. Carcass lengths for steelhead were not available, and this analysis could not be applied to steelhead.

4.3.2.3 Substrate Armor Index (A)

The presence of armoring can be detected by comparing surface and subsurface grain size distributions (Vyverberg et al. 1997). The resulting armor index (A) indicates presence/absence and magnitude of armoring. Armor index values $\leq$1 indicate the absence of armoring, and armor index values >1 indicate the presence and magnitude of armoring. The armor index was calculated as:

$$A = \frac{D_{50}Sur}{D_{50}Sub}$$, where

$D_{50}Sur$ = median gravel size of surface stratum,
$D_{50}Sub$ = median gravel size of subsurface stratum.

The armor index does not describe coarseness of the surface layer, but rather the disparity between surface and subsurface particle size distributions.

4.3.2.4 Geometric Sorting Index (sg)

The geometric sorting index (sg) reflects how well fluvial processes have concentrated particles of similar size. Gravel deposits composed of a small range of gravel sizes are considered well-sorted and have a low sg value. Gravel deposits composed of a large range of gravel sizes are considered poorly-sorted and have a high sg value. A perfectly sorted gravel deposit reportedly has a sg value of 1, and a well-sorted gravel deposit reportedly has a sg value of <2.5. A sg value of approximately 3 reportedly is considered normal, and a sg value >4.5 reportedly is considered poorly-sorted (Vyverberg et al. 1997). The geometric sorting index was calculated as:

$$sg = \left(\frac{D_{84}}{D_{16}}\right)^{0.5}$$, where

D_{84} = gravel diameter at one standard deviation where 84 percent of the gravels in the sample have a diameter less than 84 mm,
D_{16} = gravel diameter at one standard deviation where 16 percent Of the gravels in the sample have a diameter less than 16 mm.

4.3.2.5 Fine Sediment Analyses

A literature review was conducted to determine the most appropriate methods for assessing the suitability of the fine grain component of the bulk gravel samples. Kondolf (2000) outlines a nine step procedure for assessing the quality of spawning gravels, and this procedure was used as a template for the analyses of the fine grain suitability assessment. The percentage of each sample that consisted of grains <1 mm, <3 mm, and <6 mm was compared to percentages listed in literature that correspond with 50 percent embryo survival to emergence. Based on information found in Kondolf (2000), the following criteria were used to assess the suitability of fines for the spawning and embryo incubation life stage of Chinook salmon and steelhead: 1) gravels were considered suitable if ≤14 percent of a bulk gravel sample consisted of gravels with diameters <1 mm, 2) gravels were considered suitable if ≤30 percent of a bulk gravel sample consisted of gravels with diameters <3 mm, and 3) gravels were considered suitable if ≤30 percent of a bulk gravel sample consisted of gravels with diameters <6 mm.

5.0 STUDY RESULTS

5.1 INTRAGRAVEL SAMPLING

The design of the intragravel sampling methodology precluded rigorous statistical comparisons, and analyses generally were limited to descriptive statistics. Results from the permeability, dissolved oxygen concentration, water temperature, and upwelling and downwelling sampling are presented separately below.

5.1.1 Permeability

Permeabilities within Chinook salmon redds for each riffle sampled in the LFC, and associated mean permeabilities by riffle (combining sample depths) and sample depth (combining riffles), are shown in Table 5.1-1. Mean permeabilities by riffle ranged from a low of 8,156 cm/hr at Bed Rock Park Riffle to a high of 23,250 cm/hr at Gateway Riffle. Mean permeabilities generally increased with increased distance downstream. Mean permeabilities by sample depth ranged from a low of 3,056 cm/hr at 18 inches to a high of 25,437 cm/hr at 6 inches. Mean permeabilities decreased with increased sample depth. Permeabilities within Chinook salmon redds for each riffle sampled in the HFC, and associated mean permeabilities by riffle (combining sample depths) and sample depth (combining riffles), are shown in Table 5.1-2. Mean permeabilities by riffle ranged from a low of 10,300 cm/hr at Keister Riffle to a high of 19,500 cm/hr at Goose Riffle. Spatial trends in gravel mean permeabilities were not evident. Mean permeabilities by sample depth ranged from a low of 4,458 cm/hr at 18 inches to a high of 23,583 cm/hr at 6 inches. Mean permeabilities decreased with increased sample depth. Mean gravel permeabilities within Chinook salmon redds were similar between the LFC and the HFC.

Permeabilities at non-redd sites sampled in the LFC, and associated mean permeabilities by riffle (combining sample depths) and sample depth (combining riffles), are shown in Table 5.1-3. Mean permeabilities by riffle ranged from a low of 2,037 cm/hr at Hatchery Riffle to a high of 3,669 cm/hr at Eye Riffle. Mean permeability was greater at Eye Riffle than at Hatchery Riffle. Mean permeabilities by sample depth ranged from a low of 2,279 cm/hr at 6 inches to a high of 4,981 cm/hr at 18 inches. Mean permeabilities increased with increased sample depth.

Table 5.1-1. Permeabilities (cm/hr) within Chinook salmon redds in the LFC, and associated mean permeabilities by riffle (combining sample depths) and sample depth (combining riffles).

	Riffle	Site Type	6 Inches	12 Inches	18 Inches	Mean
Upstream → Downstream	Hatchery	Top	27,300	600	300	**9,200**
		Middle	38,800	5,900	600	
		Bottom	7,500	700	1,100	
	Auditorium	Top	8,700	9,500	10,500	**11,558**
		Top	32,000	1,500	200	
		Middle	13,600	14,100	4,000	
		Bottom	31,900	8,600	4,100	
	Bed Rock Park	Top	25,700	6,400	1,100	**8,156**
		Middle	31,700	700	300	
		Bottom	6,600	500	400	
	Mathews	Top	30,200	33,700	2,300	**13,067**
		Middle	29,000	1,600	600	
		Bottom	16,000	3,000	1,200	
	Aleck	Top	12,300	1,800	4,700	**12,317**
		Middle	15,600	30,200	9,300	
	Robinson	Top	40,300	20,100	1,000	**15,811**
		Middle	28,700	37,700	5,800	
		Bottom	4,700	1,400	2,600	
	Steep	Top	33,900	33,800	3,400	**23,233**
		Middle	32,600	34,500	1,200	
	Weir	Top	37,200	4,500	2,100	**18,567**
		Middle	38,500	27,700	1,400	
	Eye	Top	36,900	32,600	1,500	**17,611**
		Middle	22,400	2,800	3,800	
		Bottom	36,700	18,600	3,200	
	Gateway	Top	37,000	36,800	11,200	**23,250**
		Bottom	11,000	38,900	4,600	
	Mean		**25,437**	**15,119**	**3,056**	

Table 5.1-2. Permeabilities (cm/hr) within Chinook salmon redds in the HFC, and associated mean permeabilities by riffle (combining sample depths) and sample depth (combining riffles).

	Riffle	Site Type	6 Inches	12 Inches	18 Inches	Mean
Upstream → Downstream	Sutter Butte	Top	9,800	10,000	3,300	**13,311**
		Middle	34,900	4,600	2,400	
		Bottom	37,200	15,800	1,800	
	Upper Hour	Top	9,900	26,500	13,300	**16,100**
		Middle	11,700	12,500	400	
		Bottom	38,300	31,800	500	
	Keister	Top	32,500	6,700	5,000	**10,300**
		Middle	32,400	2,100	1,700	
		Bottom	10,200	2,000	100	
	Goose	Top	21,900	35,300	1,300	**19,500**
	MacFarland	Top	17,900	3,000	1,300	**17,650**
		Bottom	26,300	35,000	22,400	
	Mean		**23,583**	**15,442**	**4,458**	

Table 5.1-3. Permeability (cm/hr) at non-redd sites in the LFC, and associated mean permeability by riffle (combining sample depths) and sample depth (combining riffles).

	Riffle	Site Type	6 Inches	12 Inches	18 Inches	Mean
Upstream ↓ Downstream	Hatchery	Trough	778	1,164	5,225	**2,037**
		Dune	3,134	1,410	508	
	Eye	Trough	451	193	537	**3,669**
		Dune	5,572	9,929	1,047	
		N/A	1504	3,646		
		N/A	1,952	141	1	
		Dune	1,221	1,612	575	
		N/A	1,000	6,157	5,118	
		N/A	670	8,970	38,180	
		N/A	2,176	2,403	9,178	
		N/A	3,297	1,777	1,817	
		Dune	2,501	1,488	531	
		Trough	2,191	4,032	1,541	
		Dune	5,463	1,028	500	
	Mean		**2,279**	**3,139**	**4,981**	

Permeabilities were sampled at both redd and non-redd sites in Hatchery Riffle and Eye Riffle. Both of these riffles are in the LFC. The mean permeabilities by sample depth and by riffle (combining sample depths), and for each riffle, are shown in Table 5.1-4. In Hatchery Riffle at sample depths of 6 inches and 12 inches, permeabilities were highest within Chinook salmon redds. However, at a sample depth of 18 inches, permeabilities were highest at non-redd sites. Mean permeabilities, when all sample depths were combined, were highest within Chinook salmon redds. In Eye Riffle at sample depths of 6 inches and 12 inches, permeabilities were highest within Chinook salmon redds. However, at a sample depth of 18 inches, permeabilities were highest at non-redd sites. Mean permeabilities, when all sample depths were combined, were highest within Chinook salmon redds. Box and whisker plots displaying the distribution of the permeability data for redd and non-redd sites, with sample depths pooled, are shown in Figure 5.1-1. Mean permeabilities and variation were higher within Chinook salmon redds. A two sample t-test concluded that mean permeability differed between redd and non-redd sites ($p<0.001$).

Table 5.1-4. Mean permeabilities (cm/hr), by sample depth and riffle (sample depths combined), at redd and non-redd sites in Hatchery Riffle and Eye Riffle.

	Hatchery Riffle Within Redd			**Hatchery Riffle Non-Redd**			**Eye Riffle Within Redd**			**Eye Riffle Non-Redd**		
	6”	**12”**	**18”**	**6”**	**12”**	**18”**	**6”**	**12”**	**18”**	**6”**	**12”**	**18”**
By Depth	24,533	2,400	667	1,956	1,287	2,867	32,000	18,000	2,833	2,333	3,448	5,366
By Riffle	9,200			2,037			17,611			3,669		

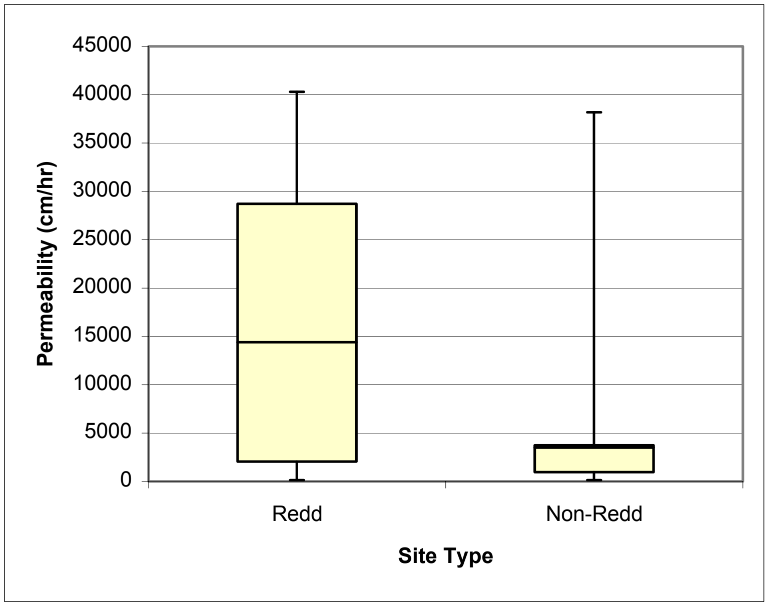

Figure 5.1-1. Box and whisker plots displaying the distribution of the permeability data for redd and non-redd sites.

A one way Analysis of Variance (ANOVA) was performed to test for differences in mean permeability among sample depths (6 inches, 12 inches, 18 inches). The test concluded that mean permeability differed among sample depths ($p<0.001$). Box and whisker plots displaying the distribution of the permeability data for each sample depth are shown in Figure 5.1-2. Mean permeabilities, and variation, decreased with gravel depth. Minimum and maximum permeabilities were similar among sample depths.

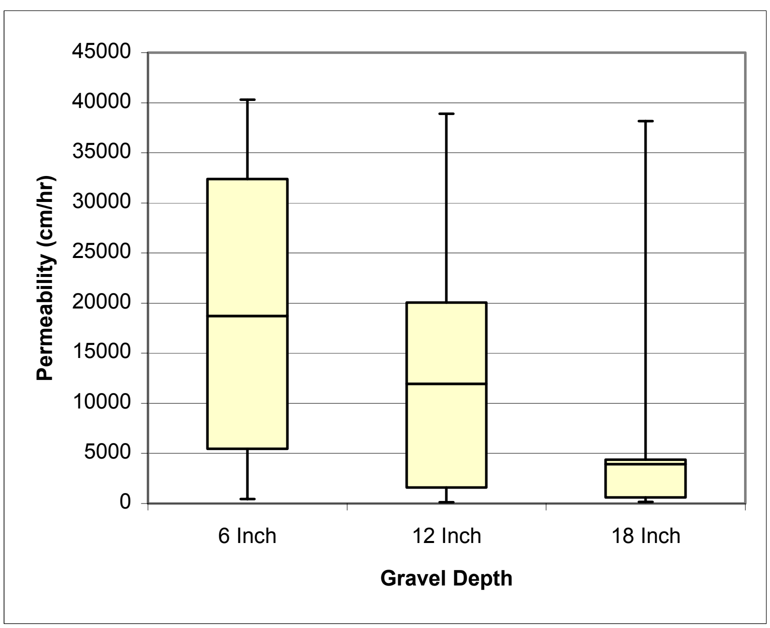

Figure 5.1-2. Box and whisker plots displaying the distribution of the permeability data for each sample depth.

Box and whisker plots displaying the distribution of the permeability data for each sample reach (LFC, HFC) are shown in Figure 5.1-3. Mean permeability, variation, and the third quartile were higher in the HFC. Minimum, maximum, and the first quartile were similar between reaches. A two sample t-test concluded that differences in mean permeability did not exist between reaches (p=0.176).

Box and whisker plots displaying the distribution of the permeability data by riffle location (top, middle, bottom) and reach (LFC, HFC) are shown in Figure 5.1-4. Mean permeability within top and middle sections of riffles was higher in the LFC. However, mean permeability in the bottom section of riffles was higher in the HFC. In the LFC, mean permeability decreased with increased downstream location. In the HFC, mean permeability was lowest in middle riffle sections, and highest in bottom riffle sections. Overall, mean permeability was highest in bottom riffle sections in the HFC. However, bottom riffle sections in the HFC were represented by the fewest samples. Variation generally was high within all sample strata.

Box and whisker plots displaying the distribution of the permeability data by site type (top, middle, bottom, dune, trough) and 6 inch sample depth are shown in Figure 5.1-5. Mean permeability was significantly higher at top, middle, and bottom site types when compared to trough and dune site types. Mean permeabilities were similar among top, middle and bottom site types, and between trough and dune site types. Of note is that top, middle, and bottom permeability data were recorded within Chinook salmon redds, and trough and dune permeability data were recorded at non-redd sites.

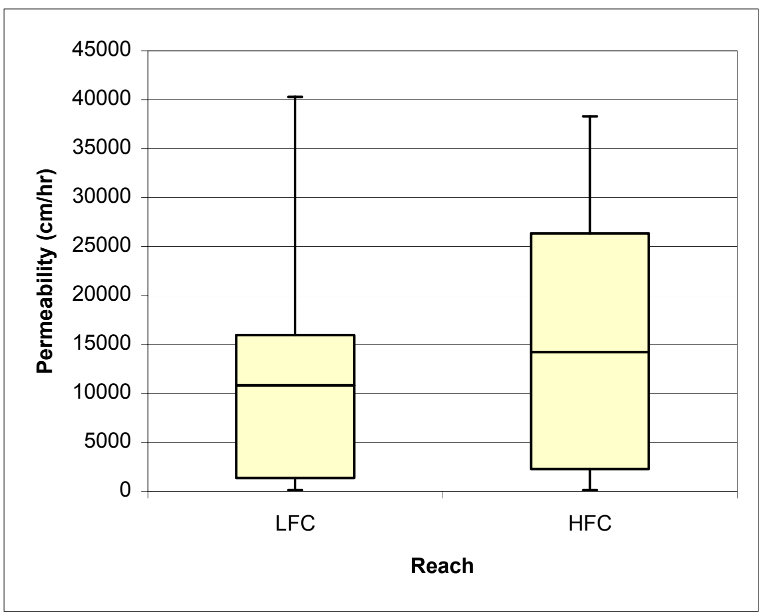

Figure 5.1-3. Box and whisker plots displaying the distribution of the permeability data for each sample reach (LFC, HFC).

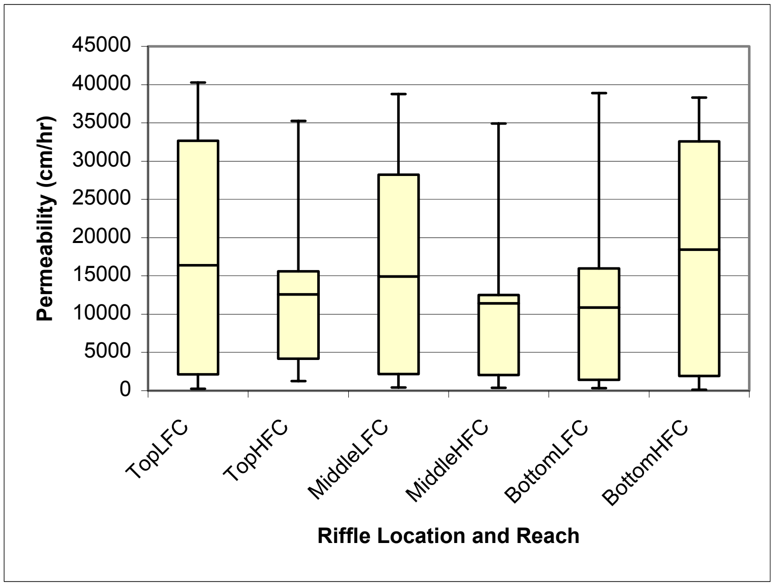

Figure 5.1-4. Box and whisker plots displaying the distribution of the permeability data by riffle location (top, middle, bottom) and reach (LFC, HFC).

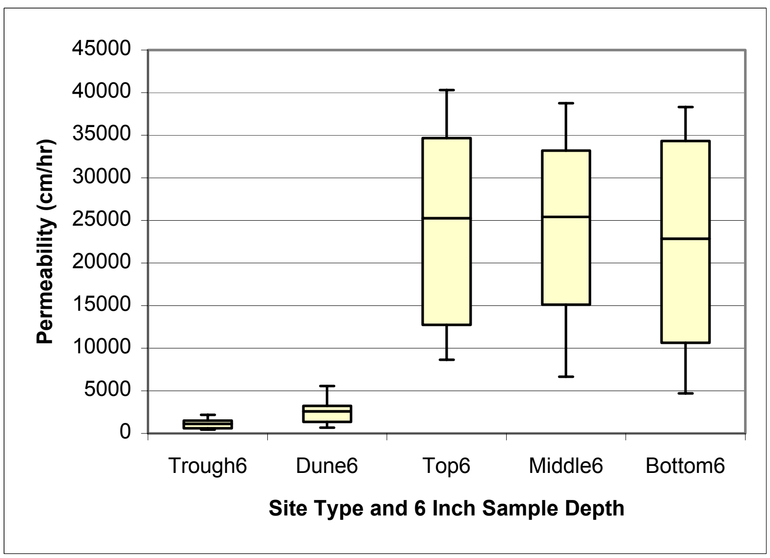

Figure 5.1-5. Box and whisker plots displaying the distribution of the permeability data by site type (top, middle, bottom, dune, trough) and 6 inch sample depth.

Box and whisker plots displaying the distribution of the permeability data by site type (top, middle, bottom, dune, trough) and 12 inch sample depth are shown in Figure 5.1-6. Mean permeability was significantly higher at top, middle, and bottom site types when compared to trough and dune site types. Mean permeability was similar among top, middle and bottom site types, and between trough and dune site types. Of note is that top, middle, and bottom permeability data were recorded within Chinook salmon redds, and trough and dune permeability data were recorded at non-redd sites.

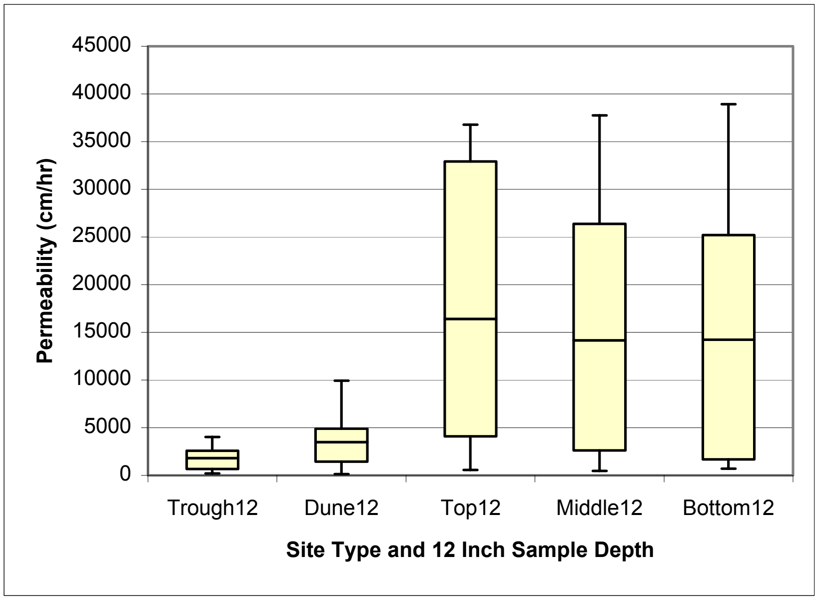

Figure 5.1-6. Box and whisker plots displaying the distribution of the permeability data by site type (top, middle, bottom, dune, trough) and 12 inch sample depth.

Box and whisker plots displaying the distribution of the permeability data by site type (top, middle, bottom, dune, trough) and 18 inch sample depth are shown in Figure 5.1-7. Mean permeabilities and variation were similar among site types. Variation was lower among top, middle, and bottom site types at 18 inches when compared to top, middle, and bottom site types at 6 inches and 12 inches.

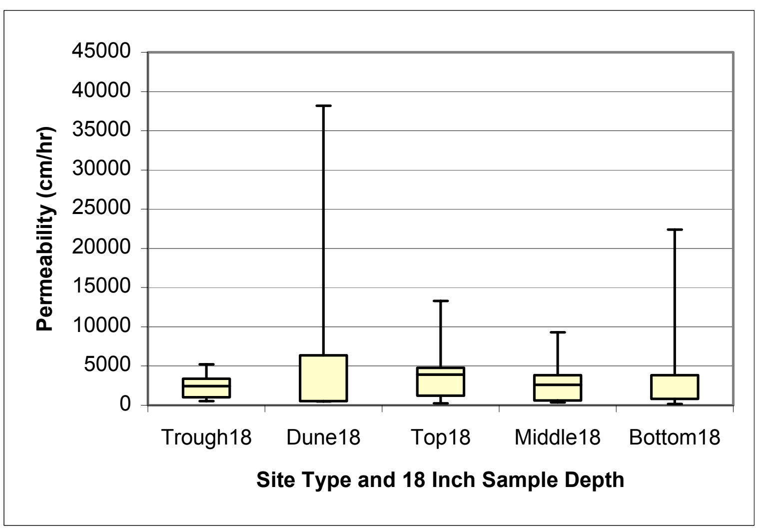

Figure 5.1-7. Box and whisker plots displaying the distribution of the permeability data by site type (top, middle, bottom, dune, trough) and 18 inch sample depth.

5.1.2 Dissolved Oxygen Concentration

Dissolved oxygen concentrations within Chinook salmon redds for each riffle sampled in the HFC, and associated mean dissolved oxygen concentrations by riffle (combining sample depths) and sample depth (combining riffles), are shown in Table 5.1-5. Mean dissolved oxygen concentrations by riffle ranged from a low of 9.9 mg/l at Goose Riffle to a high of 10.9 mg/l at Upper Hour Riffle. Spatial trends in mean dissolved oxygen concentrations were not evident. Mean dissolved oxygen concentrations by sample depth ranged from a low of 10.5 mg/l at 12 inches to a high of 10.9 mg/l at 6 inches. Mean dissolved oxygen concentrations within Chinook salmon redds showed a greater range of values in the LFC than in the HFC, including the highest and lowest values.

Dissolved oxygen concentrations within Chinook salmon redds for each riffle sampled in the LFC, and associated mean dissolved oxygen concentrations by riffle (combining sample depths) and sample depth (combining riffles), are shown in Table 5.1-6. Mean dissolved oxygen concentrations by riffle ranged from a low of 8.5 mg/l at Bed Rock Park Riffle to a high of 11.3 mg/l at Aleck Riffle. Spatial trends in mean dissolved oxygen concentrations were not evident. Mean dissolved oxygen concentrations by sample depth ranged from a low of 9.3 mg/l at 18 inches to a high of 10.6 mg/l at 6 inches. Mean dissolved oxygen concentrations decreased with increased sample depth.

Table 5.1-5. Dissolved oxygen concentrations (mg/l) within Chinook salmon redds in the HFC, and associated mean dissolved oxygen concentrations by riffle (combining sample depths) and sample depth (combining riffles).

<table>
<tr><th></th><th>Riffle</th><th>Site Type</th><th>6 Inches</th><th>12 Inches</th><th>18 Inches</th><th>Mean</th></tr>
<tr><td rowspan="13">Upstream → Downstream</td><td rowspan="3">Sutter Butte</td><td>Top</td><td>10.0</td><td>9.2</td><td>9.1</td><td rowspan="3">10.5</td></tr>
<tr><td>Middle</td><td>10.1</td><td>10.6</td><td>10.6</td></tr>
<tr><td>Bottom</td><td>12.3</td><td>11.6</td><td>11.4</td></tr>
<tr><td rowspan="3">Upper Hour</td><td>Top</td><td>11.0</td><td>11.1</td><td>11.3</td><td rowspan="3">10.9</td></tr>
<tr><td>Middle</td><td>11.1</td><td>11.3</td><td>11.2</td></tr>
<tr><td>Bottom</td><td>11.0</td><td>10.1</td><td>10.3</td></tr>
<tr><td rowspan="3">Keister</td><td>Top</td><td>11.5</td><td>10.0</td><td>10.7</td><td rowspan="3">10.8</td></tr>
<tr><td>Middle</td><td>11.3</td><td>11.0</td><td>11.1</td></tr>
<tr><td>Bottom</td><td>11.6</td><td>11.0</td><td>9.4</td></tr>
<tr><td>Goose</td><td>Top</td><td>9.7</td><td>9.3</td><td>10.7</td><td>9.9</td></tr>
<tr><td rowspan="2">MacFarland</td><td>Top</td><td>11.5</td><td>10.9</td><td>11.5</td><td rowspan="2">10.6</td></tr>
<tr><td>Bottom</td><td>9.9</td><td>10.1</td><td>9.6</td></tr>
<tr><td>Mean</td><td></td><td>10.9</td><td>10.5</td><td>10.6</td><td></td></tr>
</table>

Table 5.1-6. Dissolved oxygen concentrations (mg/l) within Chinook salmon redds in the LFC, and associated mean dissolved oxygen concentrations by riffle (combining sample depths) and sample depth (combining riffles).

	Riffle	Site Type	6 Inches	12 Inches	18 Inches	Mean
Upstream ↓ Downstream	Hatchery	Top	10.7	10.1	9.0	**9.9**
		Middle	10.6	10.7	10.2	
		Bottom	10.9	8.9	7.7	
	Auditorium	Top	11.4	11.9	11.6	**10.8**
		Top	10.1	10.3	11.7	
		Middle	12.1	11.7	11.3	
		Bottom	11.2	9.6	7.0	
	Bed Rock Park	Top	10.3	10.4	9.6	**8.5**
		Middle	10.6	9.5	10.1	
		Bottom	11.3	4.2	0.9	
	Mathews	Top	10.1	10.0	9.7	**9.0**
		Middle	9.5	9.9	9.4	
		Bottom	10.4	6.7	5.6	
	Aleck	Top	11.3	11.7	11.8	**11.3**
		Middle	11.6	12.0	9.2	
	Robinson	Top	9.7	9.4	9.7	**10.4**
		Middle	10.8	10.5	10.8	
		Bottom	11.0	10.9	10.7	
	Steep	Top	10.4	10.8	11.0	**10.4**
		Middle	10.7	10.0	9.7	
	Weir	Top	9.5	8.2	5.1	**8.8**
		Middle	10.1	10.4	9.4	
	Eye	Top	10.9	10.8	10.7	**11.0**
		Middle	11.2	10.8	10.4	
		Bottom	11.6	11.4	11.1	
	Gateway	Top	9.6	9.6	9.7	**9.6**
		Bottom	9.4	10.5	8.8	
	Mean		**10.6**	**10.0**	**9.3**	

Dissolved oxygen concentrations at non-redd sites sampled in the LFC, and associated mean dissolved oxygen concentrations by riffle (combining sample depths) and sample depth (combining riffles), are shown in Table 5.1-7. Mean dissolved oxygen concentrations by riffle ranged from a low of 9.3 mg/l at Hatchery Riffle to a high of 10.2 mg/l at Eye Riffle. Mean dissolved oxygen concentrations were greater at Eye Riffle than at Hatchery Riffle. Mean dissolved oxygen concentrations by sample depth ranged from a low of 9.3 mg/l at 18 inches to a high of 10.4 mg/l at 6 inches. Mean dissolved oxygen concentrations decreased with increased sample depth.

Dissolved oxygen concentrations were obtained at both redd and non-redd sites in Hatchery Riffle and Eye Riffle in the LFC. The mean dissolved oxygen concentrations by depth and by riffle (combining sample depths) are shown in Table 5.1-8. In Hatchery Riffle at sample depths of 6 inches and 18 inches, mean dissolved oxygen concentrations were highest within Chinook salmon redds. However, at a sample depth of 12 inches, mean dissolved oxygen concentrations were highest at non-redd sites. Within each riffle, mean dissolved oxygen concentrations, when all sample depths were combined, were highest within Chinook salmon redds. In Eye Riffle, mean dissolved oxygen concentrations within sample depth were highest at redd sites, and mean dissolved oxygen concentrations decreased with increased sample depth. Within each riffle, mean dissolved oxygen concentrations, when all sample depths were combined, were highest within Chinook salmon redds. Box and whisker plots displaying the distribution of the dissolved oxygen concentration data for redd and non-redd sites, with sample depths pooled, are shown in Figure 5.1-8. Mean dissolved oxygen concentrations and variation were higher within Chinook salmon redds. A two sample t-test concluded that mean dissolved oxygen concentration did not differ between redd and non-redd sites (p=0.540).

Table 5.1-7. Dissolved oxygen concentrations (mg/l) at non-redd sites in the LFC, and associated mean dissolved oxygen concentrations by riffle (combining sample depths) and sample depth (combining riffles).

	Riffle	Site Type	6 Inches	12 Inches	18 Inches	Mean
Upstream ↓ Downstream	Hatchery	Trough	10.5	10.0	5.3	**9.3**
		Dune	10.5	10.2	9.5	
	Eye	Trough		11.2	8.5	**10.2**
		Dune	11.2	11.2	10.4	
		N/A	9.7	9.7		
		N/A	10.5	10.3	7.4	
		Dune	11.1	10.7	10.5	
		N/A	9.9	10.1	10.1	
		N/A	11.1	11.1	11.1	
		N/A	10.4	10.0	10.1	
		N/A	9.3	9.5	8.0	
		Dune	10.1	9.5	9.7	
		Trough	10.8	10.9	10.7	
		Dune	10.5	10.5	10.2	
	Mean		**10.4**	**10.3**	**9.3**	

Table 5.1-8. Mean dissolved oxygen concentrations (mg/l), by sample depth and riffle (sample depths combined), at redd and non-redd sites in Hatchery Riffle and Eye Riffle.

	Hatchery Riffle Within Redd			Hatchery Riffle Non-Redd			Eye Riffle Within Redd			Eye Riffle Non-Redd		
	6”	12”	18”	6”	12”	18”	6”	12”	18”	6”	12”	18”
By Depth	10.8	9.9	8.9	10.5	10.1	7.4	11.2	11.0	10.7	10.4	10.4	9.7
By Riffle	9.9			9.3			11.0			10.2		

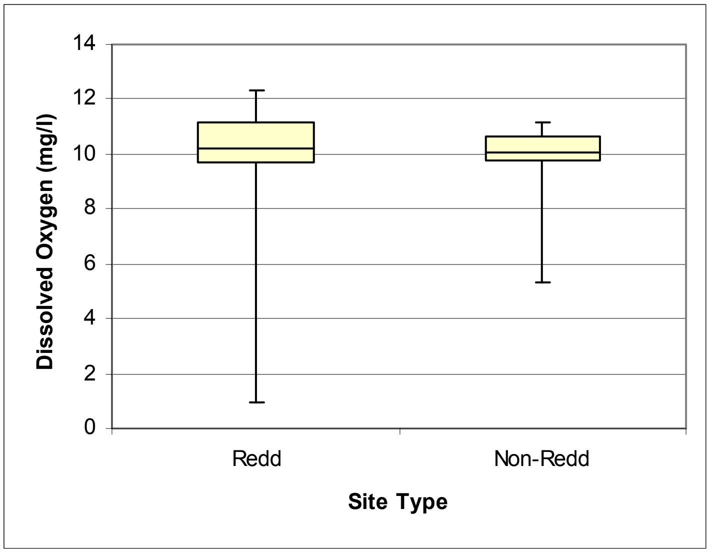

Figure 5.1-8. Box and whisker plots displaying the distribution of the dissolved oxygen concentration data for redd and non-redd sites.

A one way ANOVA was performed to test for differences in mean dissolved oxygen concentration among sample depths (6 inches, 12 inches, 18 inches). The test concluded that mean dissolved oxygen concentration differed among sample depths ($p<0.001$). Box and whisker plots displaying the distribution of the dissolved oxygen concentration data for each sample depth are shown in Figure 5.1-9. Mean dissolved oxygen concentrations decreased with gravel depth, and variation increased with gravel depth.

Box and whisker plots displaying the distribution of the dissolved oxygen concentration data for each sample reach (LFC, HFC) are shown in Figure 5.1-10. Mean dissolved oxygen concentrations were higher in the HFC. A two sample t-test concluded that mean dissolved oxygen concentration differed between reaches ($p=0.019$).

Box and whisker plots displaying the distribution of the dissolved oxygen concentration data by riffle location (top, middle, bottom) and reach (LFC, HFC) are shown in Figure 5.1-11. Mean dissolved oxygen concentrations within the top, middle, and bottom sections of riffles were higher in the LFC. In the LFC, mean dissolved oxygen concentrations decreased slightly with increased downstream location. Spatial trends were not evident in the HFC. Overall, mean dissolved oxygen concentrations were similar between and within riffle location and reach.

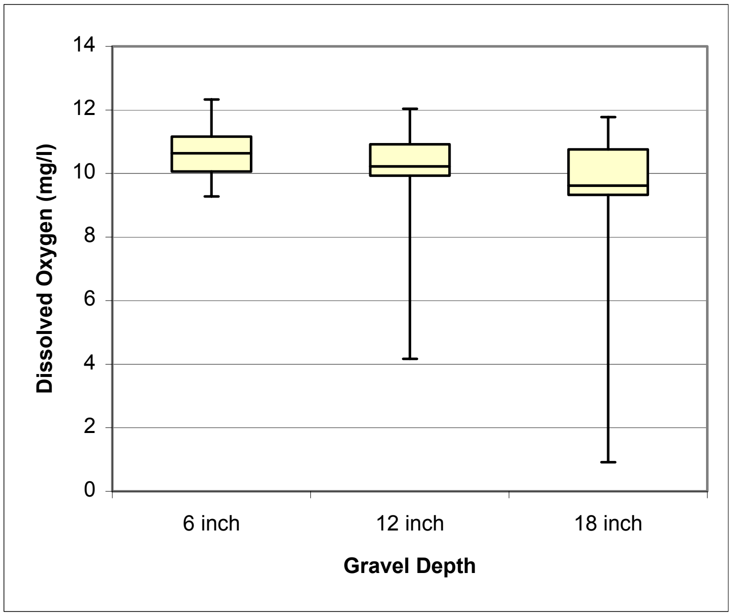

Figure 5.1-9. Box and whisker plots displaying the distribution of the dissolved oxygen concentration data for each sample depth.

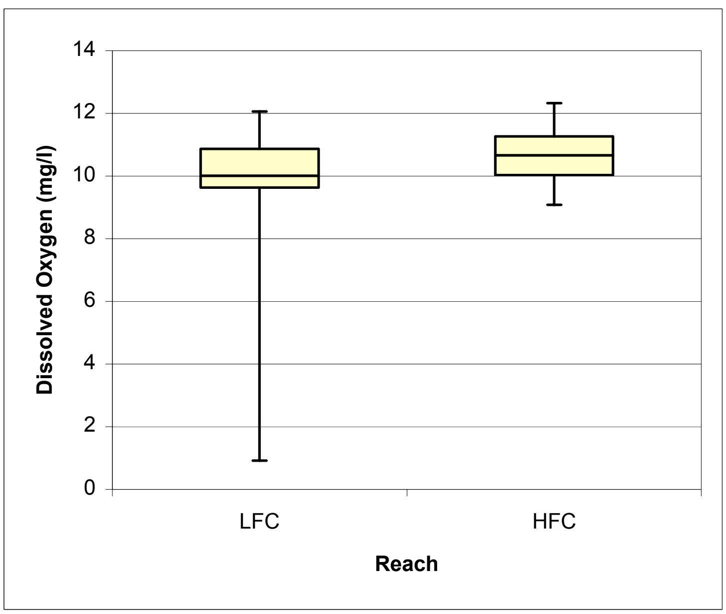

Figure 5.1-10. Box and whisker plots displaying the distribution of the dissolved oxygen concentration data for each sample reach (LFC, HFC).

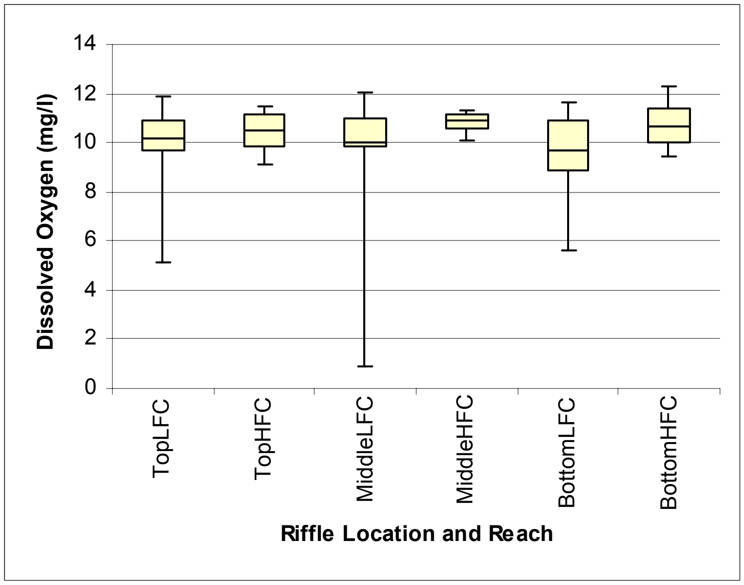

Figure 5.1-11. Box and whisker plots displaying the distribution of the dissolved oxygen concentration data by riffle location (top, middle, bottom) and reach (LFC, HFC).

Box and whisker plots displaying the distribution of the dissolved oxygen concentration data by site type (top, middle, bottom, dune, trough) and 6 inch sample depth are shown in Figure 5.1-12. Mean dissolved oxygen concentrations and variation generally were higher at top, middle, and bottom site types when compared to trough and dune site types. Of note is that top, middle, and bottom dissolved oxygen concentration data were recorded within Chinook salmon redds, and trough and dune dissolved oxygen concentration data were recorded at non-redd sites. Mean dissolved oxygen concentrations increased in riffles with increased distance downstream.

Box and whisker plots displaying the distribution of the dissolved oxygen data concentration by site type (top, middle, bottom, dune, trough) and 12 inch sample depth are shown in Figure 5.1-13. Mean dissolved oxygen concentrations were similar among site types, and spatial trends were not evident.

Box and whisker plots displaying the distribution of the dissolved oxygen concentration data by site type (top, middle, bottom, dune, trough) and 18 inch sample depth are shown in Figure 5.1-14. Mean dissolved oxygen concentrations generally were higher at top, middle, and bottom site types when compared to trough and dune site types. Mean dissolved oxygen concentrations in riffles decreased slightly with increased distance downstream.

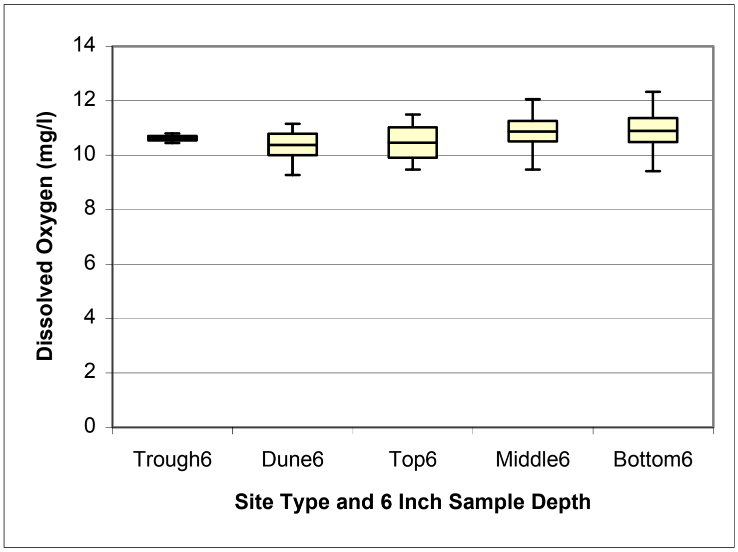

Figure 5.1-12. Box and whisker plots displaying the distribution of the dissolved oxygen concentration data by site type (top, middle, bottom, dune, trough) and 6 inch sample depth.

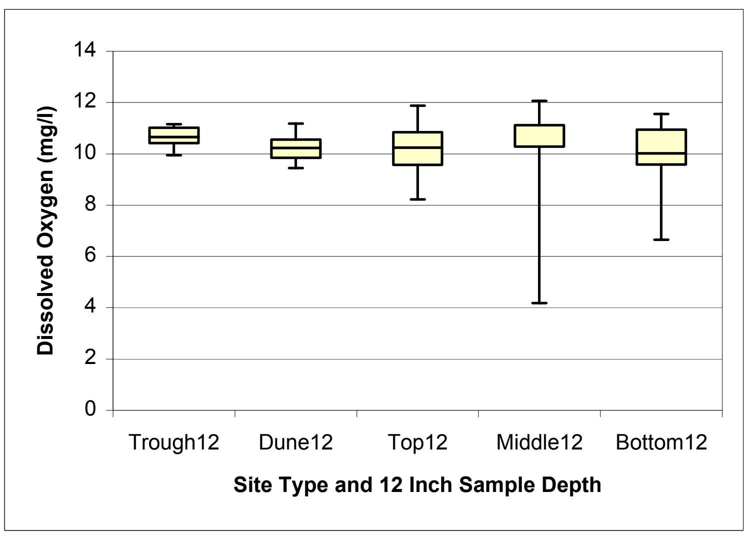

Figure 5.1-13. Box and whisker plots displaying the distribution of the dissolved oxygen concentration data by site type (top, middle, bottom, dune, trough) and 12 inch sample depth.

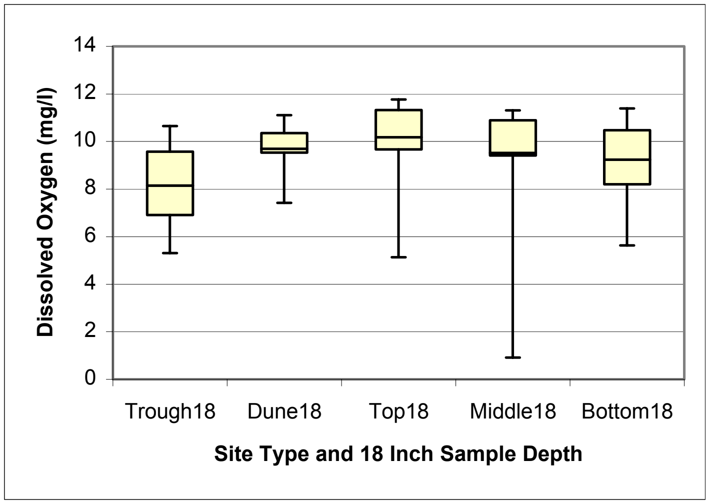

Figure 5.1-14. Box and whisker plots displaying the distribution of the dissolved oxygen concentration data by site type (top, middle, bottom, dune, trough) and 18 inch sample depth.

5.1.2.1 Diel Fluctuation in Dissolved Oxygen Concentration

The results from the dissolved oxygen concentration diel sampling are shown in Table 5.1-9. Dissolved oxygen concentrations within the water column ranged from a low of 10.17 mg/l at 1720 to a high of 12.37 mg/l at 1140. Dissolved oxygen concentrations within Chinook salmon redds ranged from a low of 10.48 mg/l at 0540 to a high of 12.06 mg/l at 1020. Dissolved oxygen concentrations generally increased from dawn to late morning, then decreased as evening approached. Differences in dissolved oxygen concentrations were slight between the water column and within Chinook salmon redds. Diel fluctuations were slight.

Table 5.1-9. Results from the Dissolved Oxygen Concentration Diel Sampling.

	Water Column		Within Chinook Salmon Redd	
Time	**Water Temperature °F**	**Dissolved Oxygen mg/l**	**Water Temperature °F**	**Dissolved Oxygen mg/l**
0535	52.50	10.47		
0540			52.50	10.48
0715	52.50	11.41		
0720			52.50	10.99
0845	52.7	11.65	52.7	11.42
1020	53.06	12.16	53.24	12.06
1140	53.42	12.37		
1143			12.1	11.99
1300	53.60	11.22	53.60	11.18
1340	53.24	10.51	53.42	10.25
1425	53.42	11.71		
1428			53.6	11.39
1720	11.7	10.17		
1723			11.7	10.57

5.1.3 Water Temperature

The water temperature data are single data points, not time series data, and do not represent temporal variation. The data were collected on different days during different times of the day. Water temperature data were collected within Chinook salmon redds from October 24, 2003 through November 13, 2003, at non-redd sites in Hatchery Riffle on September 10, 2003 and October 15, 2003, and at non-redd sites in Eye Riffle from August 6, 2003 through August 19, 2003. Due to the nature of data collection, the water temperature data were not reflective of temporal variation, should not be used as a means of comparison (i.e., comparing water temperatures at redd vs. non-redd sites), and should not be used to assess the thermal suitability for the spawning and embryo incubation life stage of Chinook salmon and steelhead. Empirical results are presented below, and offer a very general example of intragravel water temperatures for the date and times that the data were collected.

Water temperatures within Chinook salmon redds for each riffle sampled in the LFC, and associated mean water temperatures by riffle (combining sample depths) and sample depth (combining riffles), are shown in Table 5.1-10. Mean water temperatures by riffle ranged from a low of 52^{o}F (11.1^{o}C) at Weir Riffle to a high of 54.4^{o}F (12.4^{o}C) at Eye Riffle. Mean water temperatures generally were identical for all sample depths. Water temperatures within Chinook salmon redds for each riffle sampled in the HFC, and associated mean water temperatures by riffle (combining sample depths) and sample depth (combining riffles), are shown in Table 5.1-11. Mean water temperatures by riffle ranged from a low of 53.4^{o}F (11.9^{o}C) at Sutter Butte Riffle and MacFarland Riffle, to a high of 54.4^{o}F (12.4^{o}C) at Goose Riffle. Mean water temperatures generally were very similar among sample depths.

Table 5.1-10. Water temperatures (°F) within Chinook salmon redds in the LFC, and associated mean water temperatures by riffle (combining sample depths) and sample depth (combining riffles).

	Riffle	Site Type	6 Inches	12 Inches	18 Inches	Mean
Upstream ↓ Downstream	Hatchery	Top	51.3	51.3	51.3	**52.7**
		Middle	53.4	53.4	53.2	
		Bottom	53.6	53.6	53.4	
	Auditorium	Top	52.7	52.9	52.9	**53.2**
		Top	53.2	53.2	53.4	
		Middle	53.6	53.4	52.9	
		Bottom	53.4	53.2	53.1	
	Bed Rock Park	Top	51.8	52.0	52.2	**52.9**
		Middle	52.9	53.4	53.1	
		Bottom	53.8	53.4	53.2	
	Mathews	Top	51.4	51.4	51.4	**53.4**
		Middle	53.6	54.0	54.1	
		Bottom	54.7	54.9	54.9	
	Aleck	Top	53.4	53.6	53.8	**53.8**
		Middle	54.0	54.1	54.1	
	Robinson	Top	52.2	52.3	52.3	**51.8**
		Middle	51.3	51.4	51.4	
		Bottom	50.9	51.6	52.9	
	Steep	Top	52.2	52.2	52.2	**52.3**
		Middle	52.5	52.3	52.3	
	Weir	Top	52.0	52.2	52.2	**52.0**
		Middle	51.8	52.0	52.2	
	Eye	Top	54.1	54.1	54.1	**54.4**
		Middle	54.5	54.3	54.3	
		Bottom	54.7	54.7	54.7	
	Gateway	Top	52.9	52.9	52.9	**53.2**
		Bottom	53.2	53.4	53.6	
	Mean		**55.7**	**55.8**	**55.8**	

Table 5.1-11. Water temperatures (°F) within Chinook salmon redds in the HFC, and associated mean water temperatures by riffle (combining sample depths) and sample depth (combining riffles).

	Riffle	Site Type	6 Inches	12 Inches	18 Inches	Mean
Upstream ↓ Downstream	Sutter Butte	Top	54.5	54.5	54.5	**53.4**
		Middle	52.9	52.9	53.1	
		Bottom	52.7	52.7	52.9	
	Upper Hour	Top	53.6	53.6	53.6	**54.0**
		Middle	54.0	54.1	54.1	
		Bottom	54.1	54.1	54.3	
	Keister	Top	54.0	54.0	54.0	**54.1**
		Middle	54.1	54.1	54.1	
		Bottom	54.1	54.3	54.5	
	Goose	Top	53.8	54.0	55.6	**54.4**
	MacFarland	Top	52.9	53.1	53.2	**53.4**
		Bottom	53.8	53.8	53.6	
	Mean		**53.2**	**53.3**	**53.4**	

Water temperatures at non-redd sites sampled in the LFC, and associated mean water temperatures by riffle (combining sample depths) and sample depth (combining riffles), are shown in Table 5.1-12. Mean water temperatures by riffle ranged from a low of 54.1°F (12.3°C) at Hatchery Riffle to a high of 64.2°F (17.9°C) at Eye Riffle. Water temperature data at Hatchery Riffle and Eye Riffle were recorded during different months. Mean water temperatures were very similar among sample depths.

Table 5.1-12. Water temperatures (°F) at non-redd sites in the LFC, and associated mean water temperatures by riffle (combining sample depths) and sample depth (combining riffles).

	Riffle	Site Type	6 Inches	12 Inches	18 Inches	Mean
Upstream ↓ Downstream	Hatchery	Trough	53.4	54.0	54.1	**54.1**
		Dune	54.5	54.5	54.3	
	Eye	Trough	65.7	65.7	65.8	**64.2**
		Dune	66.6	66.6	66.2	
		N/A	63.3	63.7		
		N/A	64.6	65.1	65.8	
		Dune	66.4	66.2	66.6	
		N/A	62.4	62.8	63.1	
		N/A	64.2	64.2	64.6	
		N/A	64.6	64.6	64.8	
		N/A	65.8	65.5	65.3	
		Dune	59.9	59.9	61.2	
		Trough	61.9	62.1	62.2	
		Dune	63.0	63.0	63.0	
	Mean		**62.6**	**62.7**	**62.8**	

Water temperatures were obtained at both redd and non-redd sites in Hatchery Riffle and Eye Riffle in the LFC. The mean water temperatures by sample depth and by riffle (combining sample depths), and for each riffle, are shown in Table 5.1-13. In Hatchery Riffle, the mean water temperatures were slightly higher at non-redd sites, and very similar within site types and among sample depths. In Eye Riffle, mean water temperatures were similar within site types and among sample depths, but were higher at non-redd sites. However, water temperature data in Eye Riffle were collected at non-redd sites between August 6, 2003 and August 19, 2003, and at redd sites between October 24, 2003 through November 13, 2003.

Table 5.1-13. Mean water temperatures (°F), by sample depth and riffle (sample depths combined), at redd and non-redd sites in Hatchery Riffle and Eye Riffle.

	Hatchery Riffle Within Redd			**Hatchery Riffle Non-Redd**			**Eye Riffle Within Redd**			**Eye Riffle Non-Redd**		
	6”	**12”**	**18”**	**6”**	**12”**	**18”**	**6”**	**12”**	**18”**	**6”**	**12”**	**18”**
By Depth	52.8	52.8	52.6	54.0	54.2	54.2	54.4	54.4	54.4	64.0	64.1	64.4
By Riffle	52.7			54.1			54.4			64.2		

5.1.4 Upwelling and Downwelling Potential

Empirical results from the upwelling and downwelling potential sampling are shown in Table 5.1-14. Cells highlighted in red indicate downwelling potential. Values represent the difference between the height of the water column inside of the standpipe and the height of the water column from the river bed to the surface of the water. A total of 159 upwelling and downwelling potential samples were collected (53 samples at each sample depth), and downwelling potential occurred in 32 of the samples (20 percent).

Table 5.1-14. Empirical results from the upwelling and downwelling potential sampling in the lower Feather River. Cells highlighted with red indicate downwelling potential.

	Riffle	Site Type	HFC/LFC	In Redd Y/	Upwelling and Downwelling Potential (cm		
					6"	12"	18"
Upstream ↓ Downstream	Hatchery	Trough	LFC	N	0.76	1.83	13.41
		Dune	LFC	N	0.61	1.22	2.44
		Top	LFC	Y	-2.13	0.30	1.07
		Middle	LFC	Y	0.00	0.30	-0.61
		Bottom	LFC	Y	0.30	0.61	-0.61
	Auditorium	Top	LFC	Y	-0.30	0.76	1.83
		Top	LFC	Y	-0.76	1.68	1.37
		Middle	LFC	Y	-0.76	0.91	0.91
		Bottom	LFC	Y	-0.46	0.15	0.00
	Bed Rock Park	Top	LFC	Y	1.22	0.61	1.83
		Bottom	LFC	Y	0.00	0.61	0.91
		Middle	LFC	Y	0.00	0.91	1.52
	Mathews	Top	LFC	Y	-0.91	-0.46	1.22
		Middle	LFC	Y	0.91	0.00	1.07
		Bottom	LFC	Y	0.15	1.52	-0.76
	Aleck	Top	LFC	Y	0.91	0.76	4.27
		Middle	LFC	Y	0.46	0.30	0.30
	Robinson	Top	LFC	Y	0.00	0.61	0.61
		Middle	LFC	Y	0.00	0.00	0.91
		Bottom	LFC	Y	0.00	-0.30	0.00
	Steep	Top	LFC	Y	0.46	0.30	0.30
		Middle	LFC	Y	1.22	0.46	1.22
	Weir	Top	LFC	Y	-0.46	0.30	0.00
		Middle	LFC	Y	-1.22	-1.52	0.30
	Eye	Trough	LFC	N	0.00	1.22	1.83
		Dune	LFC	N	1.83	10.67	2.74
		N/A	LFC	N	0.91	5.18	0.00
		N/A	LFC	N	-0.30	0.30	32.92
		Dune	LFC	N	0.91	1.52	4.57
		N/A	LFC	N	4.57	8.23	8.23
		N/A	LFC	N	0.61	9.91	12.80
		N/A	LFC	N	3.96	3.05	1.22
		N/A	LFC	N	-2.44	1.83	-6.10
		Dune	LFC	N	-1.83	3.05	4.27
		Trough	LFC	N	1.52	8.53	11.28
		Dune	LFC	N	4.88	6.10	8.84
		Top	LFC	Y	-1.22	0.61	0.76
		Middle	LFC	Y	1.22	0.91	0.61
		Bottom	LFC	Y	0.76	0.00	0.76
	Gateway	Top	LFC	Y	1.83	0.46	-11.13
		Bottom	LFC	Y	-1.52	-1.22	-3.66
	Sutter Butte	Top	HFC	Y	0.00	-3.05	-0.61
		Middle	HFC	Y	-0.61	0.91	0.30
		Bottom	HFC	Y	1.52	0.30	1.83
	Upper Hour	Top	HFC	Y	-0.61	3.35	3.35
		Middle	HFC	Y	0.00	0.30	1.22
		Bottom	HFC	Y	-0.30	-0.61	0.00
	Keister	Top	HFC	Y	-2.13	0.61	1.83
		Middle	HFC	Y	-0.30	1.22	4.57
		Bottom	HFC	Y	1.52	0.61	0.00
	Goose	Top	HFC	Y	0.91	3.51	2.44
	McFarland	Top	HFC	Y	-1.07	8.84	4.88
		Bottom	HFC	Y	0.91	1.83	2.13

In the LFC, 123 upwelling and downwelling potential samples were collected, and downwelling potential occurred in 23 of the samples (19 percent). Of the 23 samples where downwelling potential occurred, 13 occurred at a sample depth of 6 inches (57 percent), four occurred at a sample depth of 12 inches (17 percent), and six occurred at a sample depth of 18 inches (26 percent). Forty two upwelling and downwelling potential samples were collected at non-redd sites in the LFC, and downwelling potential occurred in four of the samples (10 percent). However, it is important to note that sampling at non-redd sites was not evenly distributed among riffles in the LFC. Non-redd sampling was conducted in two of the 10 riffles. Eighty one upwelling and downwelling potential samples were collected at redd sites in the LFC, and downwelling potential occurred in 19 of the samples (23 percent). Of the 19 samples where downwelling potential occurred at redd sites, eight occurred in top site type (42 percent), four occurred in middle site type (21 percent), and seven occurred in bottom site type (37 percent).

In the HFC, 36 upwelling and downwelling potential samples were collected at redd sites, and downwelling potential occurred in nine of the samples (19 percent). Of the nine samples where downwelling potential occurred, six occurred at a sample depth of 6 inches (67 percent), two occurred at a sample depth of 12 inches (22 percent), and one occurred at a sample depth of 18 inches (11 percent). Of the nine samples where downwelling potential occurred, five occurred in top site type (56 percent), two occurred at middle site type (22 percent), and two occurred at bottom site type (22 percent). Non-redd sites were not sampled in the HFC.

A one way ANOVA was performed to test for differences in the upwelling and downwelling potential among sample depths (6 inches, 12 inches, 18 inches). The test concluded that the upwelling and downwelling potential differed among sample depths ($p=0.006$). A one way ANOVA was performed to test for differences in the upwelling and downwelling potential among sample depths (6 inches, 12 inches, 18 inches) in the LFC. The test concluded that the upwelling and downwelling potential did not differ among sample depths ($p=0.020$) in the LFC. A one way ANOVA was performed to test for differences in the upwelling and downwelling potential among sample depths (6 inches, 12 inches, 18 inches) in the HFC. The test concluded that the upwelling and downwelling potential did not differ among sample depths ($p=0.034$). Sample depths were pooled by reach, and a two sample t-test was used to test for differences in the upwelling and downwelling potential between the LFC and the HFC. The test concluded that the upwelling and downwelling potential did not differ between the LFC and the HFC ($p=0.540$).

Results from the upwelling and downwelling potential sampling were overlayed on aerial photos, and can be located in Figures A1 through A16 in Appendix A.

5.2 BULK GRAVEL SAMPLING

5.2.1 Gravel Size Distribution Curves

Gravel size distribution curves were constructed for each site and for each stratum, and are located in Figures B1 through B27 in Appendix B. The gravel size distribution curve for Hatchery Riffle is provided as an example in Figure 5.2-1. The gravel distribution curves are useful for visual interpretation of differences in grave size distribution between surface and subsurface bulk gravel samples, and for visual interpretation of the suitability (based on suitability curves developed by Vyverberg et al. 1997) of surface and subsurface gravel strata.

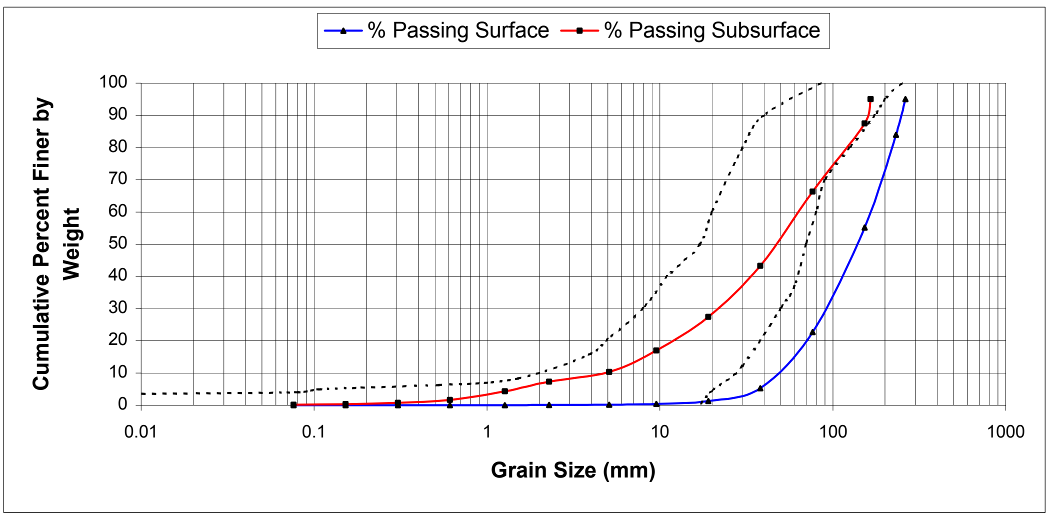

Figure 5.2-1. Gravel size distribution curve for Hatchery Riffle.

In the LFC, within site comparisons showed that surface samples consisted of a higher percentage of coarser gravels, across all gravel sizes, than did subsurface samples. Three of the 13 surface samples generally were within the range of suitability (Auditorium Riffle RM 65.77, Steep Riffle RM 60.70, and Weir Riffle RM 60.49) as defined by Vyverberg et al. (1997). The gravel size distribution of surface samples for gravels with diameters up to approximately 20 mm were within the range of suitability at all 13 sample sites, but the gravel size distribution for gravels with diameters exceeding approximately 20 mm generally were outside of the range of suitability and were coarser than the suitability range suggested by the suitability curves. All of the 13 subsurface samples generally were within the range of suitability. At five of the 13 subsurface sample sites, the gravel size distribution for gravels with diameters approximately between 0.5 mm and 9 mm were outside of the range of suitability, and gravels in this size range accounted for a higher percentage of the sample than is suitable as suggested by the suitability curves (too many fines with diameters between 0.5 mm and 9 mm). Spatial trends in gravel size distribution were not evident (Figure 5.2-2).

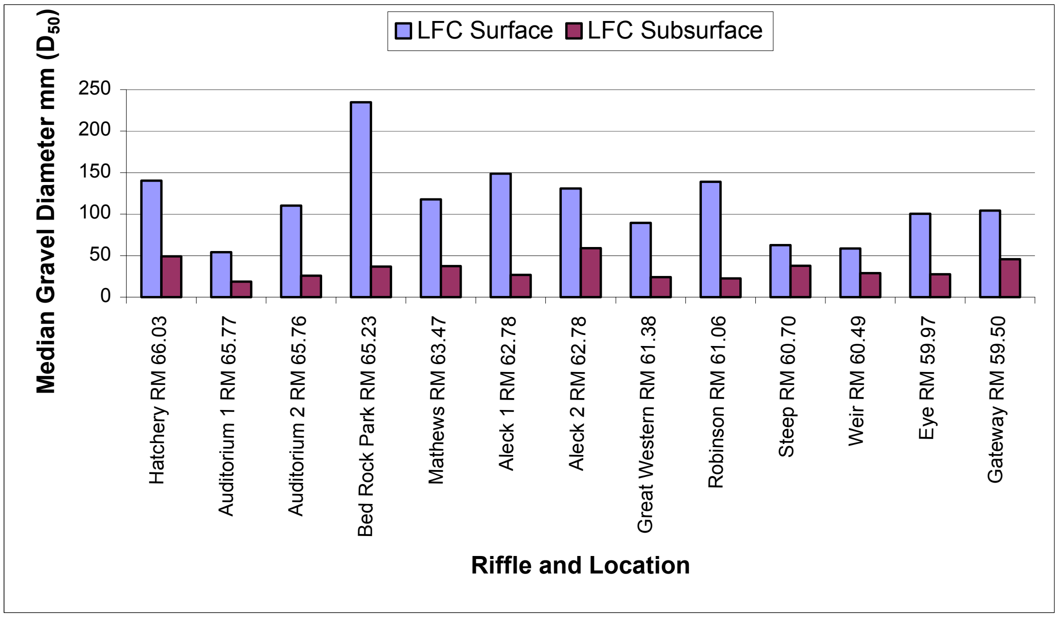

Figure 5.2-2. Spatial trends in gravel size distributions in the LFC between surface and subsurface samples.

In the HFC, within site comparisons showed that surface samples consisted of a higher percentage of coarser gravels, generally across all gravel sizes, than did subsurface samples. Eleven of the 14 surface samples generally were within the range of suitability as defined by Vyverberg et al. (1997). At sites where surface samples were considered unsuitable, the gravel size distribution for gravels with diameters approximately exceeding 30 mm fell outside of the range of suitability, and were coarser than the suitability range suggested by the suitability curves. Ten of the 14 subsurface samples generally were within the range of suitability. At sites where subsurface samples were considered unsuitable, the gravel size distribution for gravels with diameters approximately between 0.7 mm and 11 mm fell outside of the range of suitability, and were finer than the suitability range suggested by the suitability curves. Spatial trends in gravel size distribution were not evident (Figure 5.2-3).

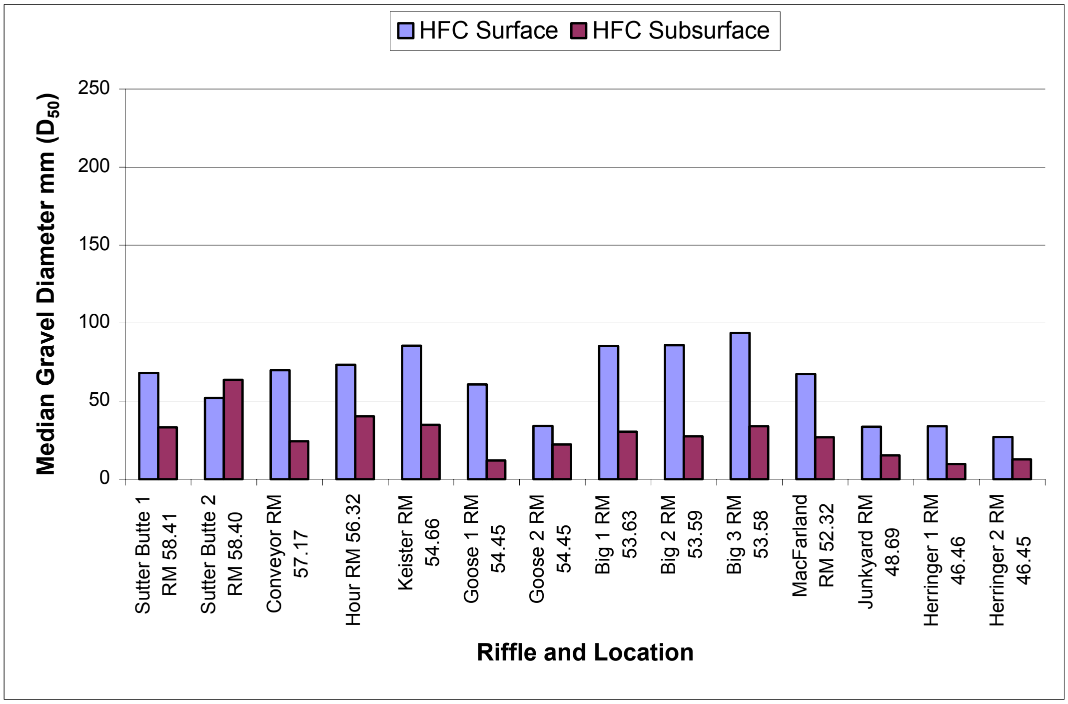

Figure 5.2-3. Spatial trends in gravel size distributions in the HFC between surface and subsurface samples.

The between reach (LFC vs. HFC) comparisons of surface sample gravel size distribution shows that gravels generally were coarser in the LFC, and that a greater number of surface samples in the HFC had gravel size distributions that were within the range of suitability as defined by Vyverberg et al. (1997) (Figure 5.2-4). The between reach comparison of subsurface sample gravel size distribution shows similar distributions between the LFC and HFC (Figure 5.2-5). A higher percentage of subsurface gravel distributions were within the range of suitability when compared to surface samples.

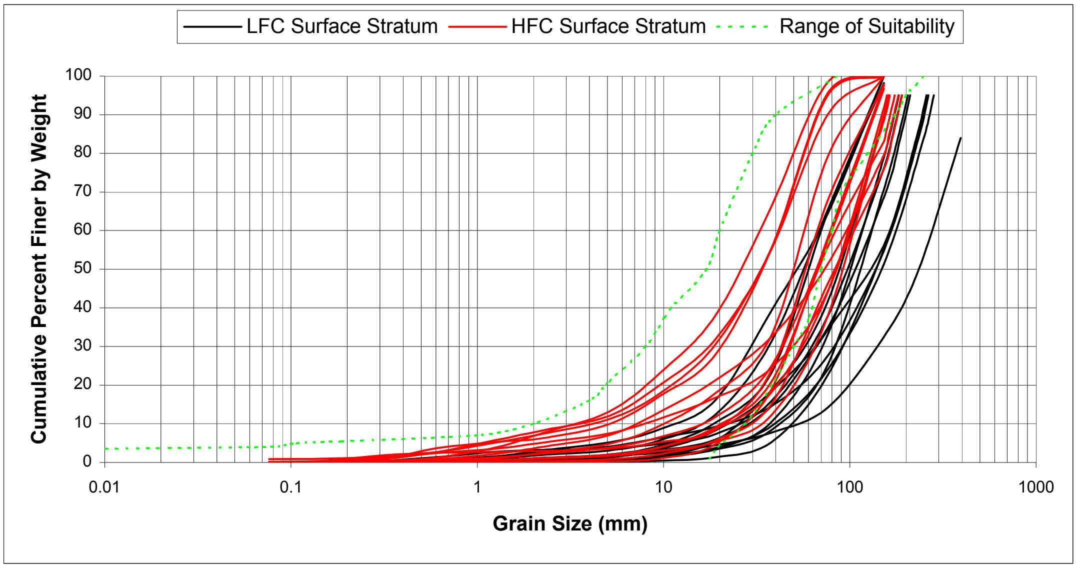

Figure 5.2-4. The between reach (LFC vs. HFC) comparison of surface sample gravel size distributions.

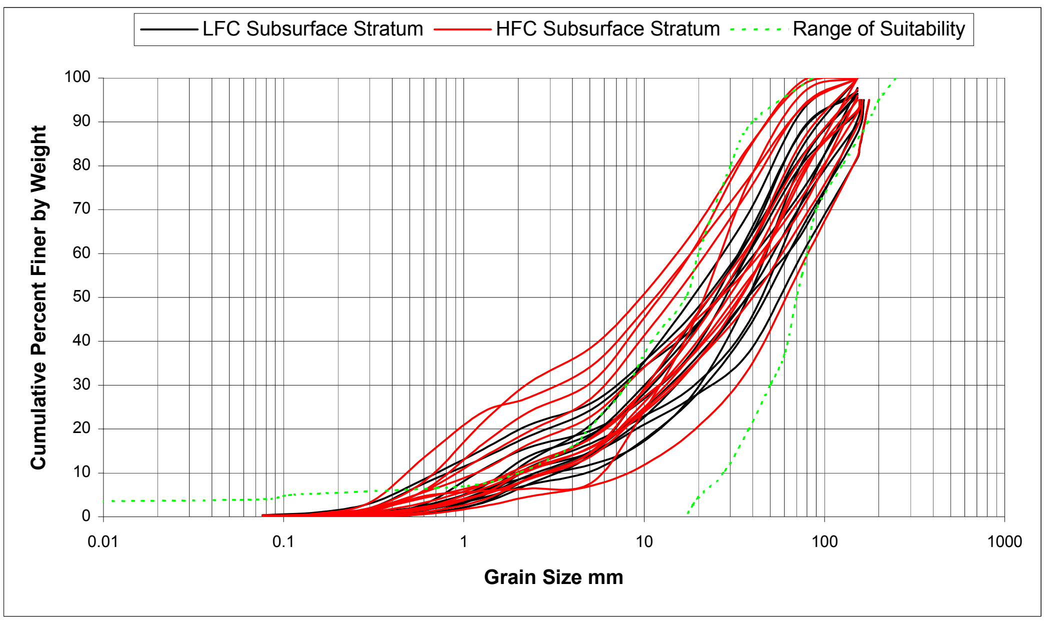

Figure 5.2-5. The between reach (LFC vs. HFC) comparison of subsurface sample gravel size distributions.

5.2.2 Median Gravel Diameter (D_{50})

The median gravel diameter (D_{50}) by sample site and gravel stratum (surface, subsurface) is shown in Table 5.2-1. The location of each riffle is provided in river miles to indicate spatial positioning between riffles. In the LFC, the within site comparisons of median gravel diameter between surface and subsurface strata showed that the median gravel diameter of surface samples were greater than the median gravel diameter of subsurface samples at all sample sites. The among site comparisons of median gravel diameter between surface and subsurface strata showed that the smallest median gravel diameter among surface samples (54.2 mm at Auditorium Riffle site 1) was greater than the median gravel diameter of 12 of the 13 subsurface samples. Spatial trends in median diameter were not evident as shown in Figure 5.2-2.

In the HFC, the within site comparisons of median gravel diameter between surface and subsurface strata showed that the median gravel diameter of surface samples were greater than the median gravel diameter of subsurface samples at 13 of the 14 sample sites. The among site comparisons of median gravel diameter between surface and subsurface strata showed that the median gravel diameter of surface samples (54.2 mm at Auditorium Riffle site 1) generally were greater than the median gravel diameter of subsurface samples. Spatial trends in median gravel diameter were not evident as shown in Figure 5.2-3. Median gravel diameter comparisons between river reach (LFC, HFC) and sample strata (surface, subsurface) were made using a two sample t-test. Results from all comparisons are shown in Table 5.2-2. Median gravel diameter did not differ between the LFC subsurface samples and the HFC subsurface samples ($p=0.226$). Median gravel diameters differed across all other combinations tested.

Table 5.2-1. Median gravel diameter (D_{50}) mm for each sample site and sample stratum (surface, subsurface), and location of each sample site by riffle and river mile (RM).

	Sample Riffle	River Mile	Surface D_{50} (mm)	Subsurface D_{50} (mm)
LFC	Hatchery	66.03	140.2	49.2
	Auditorium Site 1	65.77	54.2	18.6
	Auditorium Site 2	65.76	110.3	25.7
	Bed Rock Park	65.23	234.7	36.7
	Mathews	63.47	117.7	37.6
	Aleck Site 1	62.78	148.7	26.9
	Aleck Site 2	62.78	130.8	59.0
	Great Western	61.38	89.4	24.1
	Robinson	61.06	139.0	22.7
	Steep	60.70	62.6	37.7
	Weir	60.49	58.9	29.2
	Eye	59.97	100.3	27.5
	Gateway	59.50	104.2	45.6
HFC	Sutter Butte Site 1	58.41	68.2	33.2
	Sutter Butte Site 2	58.40	52.1	63.7
	Conveyor	57.17	69.8	24.2
	Hour	56.32	73.3	40.3
	Keister	54.66	85.5	34.9
	Goose Site 1	54.45	60.6	12.0
	Goose Site 2	54.45	34.2	22.2
	Big Site 1	53.63	85.4	30.4
	Big Site 2	53.59	85.9	27.5
	Big Site 3	53.58	93.8	34.0
	MacFarland	52.32	67.5	27.0
	Junkyard	48.69	33.6	15.3
	Herringer Site 1	46.46	34.0	9.6
	Herringer Site 2	46.45	27.0	12.7

Table 5.2-2. Probability values from two sample t-tests comparing median gravel diameter by river reach (LFC, HFC) and sample stratum (surface, subsurface). Red highlight notes the only comparison where differences were not detected.

	LFC Surface Samples	LFC Subsurface Samples	HFC Surface Samples	HFC Subsurface Samples
LFC Surface Samples	N/A	p<0.001	p<0.01	p<0.001
LFC Subsurface Samples	p<0.001	N/A	p<0.001	p=0.226
HFC Surface Samples	p<0.01	p<0.001	N/A	p<0.001
HFC Subsurface Samples	p<0.001	p=0.226	p<0.001	N/A

5.2.3 Substrate Armor Index (A)

The substrate armoring index values (A) by sample site and gravel stratum (surface, subsurface) are shown in Table 5.2-3. The location of each riffle is provided in river miles to indicate spatial positioning between riffles. In the LFC, armor index values averaged 3.6 and ranged from 1.7 to 6.4. Seven of the 13 sample sites had armor index values exceeding 3, and all sites were armored as reflected in index values exceeding 1. In the HFC, the armor index values averaged 2.6 and ranged from 0.8 to 5.1. Three of the 14 sample sites had armor index values exceeding 3, and 13 of the 14 sample sites were armored as reflected in index values exceeding 1. Spatial trends in armor index values within reach (LFC, HFC) were not evident (Figure 5.2-6). However, armor index values in the HFC generally were lower than armor index values in the LFC.

Table 5.2-3. Armor index values (A) for each sample site, and location of each sample site by riffle and river mile.

	Sample Riffle	River Mile	Surface D_{50} (mm)	Subsurface D_{50} (mm)	Armor Index (A)
LFC	Hatchery	66.03	140.2	49.2	2.9
	Auditorium Site 1	65.77	54.2	18.6	2.9
	Auditorium Site 2	65.76	110.3	25.7	4.3
	Bed Rock Park	65.23	234.7	36.7	6.4
	Mathews	63.47	117.7	37.6	3.1
	Aleck Site 1	62.78	148.7	26.9	5.5
	Aleck Site 2	62.78	130.8	59.0	2.2
	Great Western	61.38	89.4	24.1	3.7
	Robinson	61.06	139.0	22.7	6.1
	Steep	60.70	62.6	37.7	1.7
	Weir	60.49	58.9	29.2	3.7
	Eye	59.97	100.3	27.5	2.0
	Gateway	59.50	104.2	45.6	2.3
HFC	Sutter Butte Site 1	58.41	68.2	33.2	2.1
	Sutter Butte Site 2	58.40	52.1	63.7	0.8
	Conveyor	57.17	69.8	24.2	2.9
	Hour	56.32	73.3	40.3	1.8
	Keister	54.66	85.5	34.9	2.5
	Goose Site 1	54.45	60.6	12.0	5.1
	Goose Site 2	54.45	34.2	22.2	1.5
	Big Site 1	53.63	85.4	30.4	3.1
	Big Site 2	53.59	85.9	27.5	2.8
	Big Site 3	53.58	93.8	34.0	2.8
	MacFarland	52.32	67.5	27.0	2.5
	Junkyard	48.69	33.6	15.3	2.2
	Herringer Site 1	46.46	34.0	9.6	3.5
	Herringer Site 2	46.45	27.0	12.7	2.1

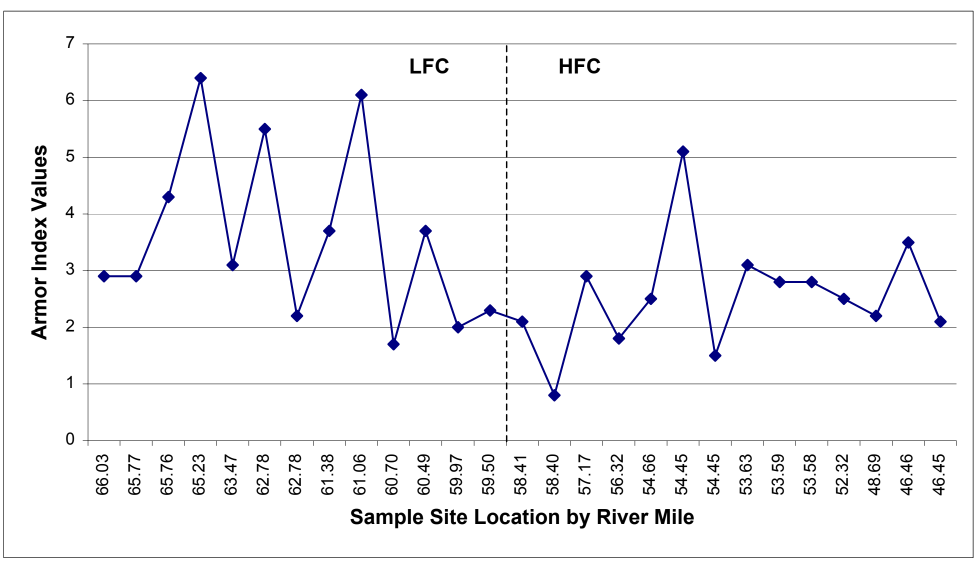

Figure 5.2-6. Armor index values by sample location and reach.

5.2.4 Geometric Sorting Index (sg)

The geometric sorting index values (sg) for the surface stratum presented by sample site are shown in Table 5.2-4. The location of each riffle is provided in river miles to indicate spatial positioning between riffles. In the LFC, sg values averaged 2.3 and ranged from 1.6 to 3.1. In the HFC, sg values averaged 3.2 and ranged from 1.7 to 6.2.

The geometric sorting index values (sg) for the subsurface stratum presented by sample site are shown in Table 5.2-5. The location of each riffle is provided in river miles to indicate spatial positioning between riffles. In the LFC, sg values averaged 13.3 and ranged from 5.1 to 30.4. In the HFC, sg values averaged 13.7 and ranged from 3.5 to 35.7.

The sg values by sample stratum and reach (LFC, HFC) are shown in Figure 5.2-7. Surface samples in the LFC and HFC had lower sg values when compared to subsurface sg values, indicating that surface gravel samples consisted of a smaller range of gravel sizes (well-sorted) than subsurface samples. Spatial trends within stratum and between reach were slight, with sg values in the HFC generally being higher than sg values in the LFC.

Table 5.2-4. Geometric sorting index values (sg) for each surface stratum sample, and sample site location by riffle and river mile.

	Sample Riffle	River Mi	Surface D_{16} (mm	Surface D_{84} (mm)	Geometric Sorting Ind (sg)
LFC	Hatchery	66.03	61.6	231.9	1.9
	Auditorium Site 1	65.77	18.8	118.1	3.1
	Auditorium Site 2	65.76	34.5	186.6	2.7
	Bed Rock Park	65.23	83.6	394.2	2.4
	Mathews	63.47	55.1	181.2	1.6
	Aleck Site 1	62.78	55.2	249.5	2.3
	Aleck Site 2	62.78	40.8	227.8	2.8
	Great Western	61.38	33.1	143.5	2.2
	Robinson	61.06	43.1	233.8	2.7
	Steep	60.70	27.4	119.9	2.2
	Weir	60.49	22.6	117.1	2.6
	Eye	59.97	38.2	168.1	2.2
	Gateway	59.50	47.3	162.2	1.7
HFC	Sutter Butte Site 1	58.41	34.0	126.2	1.9
	Sutter Butte Site 2	58.40	16.8	93.7	2.8
	Conveyor	57.17	30.0	154.1	2.6
	Hour	56.32	12.9	160.9	6.2
	Keister	54.66	39.1	168.6	2.2
	Goose Site 1	54.45	28.2	117.2	2.1
	Goose Site 2	54.45	8.8	65.1	3.7
	Big Site 1	53.63	33.6	139.9	2.1
	Big Site 2	53.59	43.5	143.7	1.7
	Big Site 3	53.58	17.7	144.6	4.1
	MacFarland	52.32	25.0	127.8	2.6
	Junkyard	48.69	7.3	65.5	4.5
	Herringer Site 1	46.46	6.4	59.0	4.6
	Herringer Site 2	46.45	8.3	69.5	4.2

Table 5.2-5. Geometric sorting index values (sg) for each subsurface stratum sample, and sample site location by riffle and river mile.

	Sample Riffle	River Mile	Subsurface D_{16} (mm)	Subsurface D_{84} (mm)	Geometric Sorting Index (sg)
LFC	Hatchery	66.03	8.9	140.0	7.9
	Auditorium Site 1	65.77	3.4	61.8	9.1
	Auditorium Site 2	65.76	3.5	69.4	9.9
	Bed Rock Park	65.23	5.8	128.3	11.0
	Mathews	63.47	5.6	133.0	11.8
	Aleck Site 1	62.78	4.0	98.2	12.2
	Aleck Site 2	62.78	6.3	156.4	12.4
	Great Western	61.38	5.7	69.3	6.1
	Robinson	61.06	1.4	84.1	30.1
	Steep	60.70	8.9	90.2	5.1
	Weir	60.49	2.4	75.2	15.5
	Eye	59.97	1.8	110.2	30.4
	Gateway	59.50	4.7	110.9	11.8
HFC	Sutter Butte Site 1	58.41	5.1	116.2	11.4
	Sutter Butte Site 2	58.40	14.7	156.0	5.3
	Conveyor	57.17	5.5	84.5	7.7
	Hour	56.32	6.1	134.2	11.0
	Keister	54.66	5.2	97.4	9.3
	Goose Site 1	54.45	0.8	53.9	35.7
	Goose Site 2	54.45	7.5	52.1	3.5
	Big Site 1	53.63	5.7	101.5	9.0
	Big Site 2	53.59	4.2	101.0	12.0
	Big Site 3	53.58	2.2	119.6	27.4
	MacFarland	52.32	4.3	73.0	8.5
	Junkyard	48.69	1.7	57.0	16.8
	Herringer Site 1	46.46	1.2	38.1	15.4
	Herringer Site 2	46.45	1.0	37.7	18.9

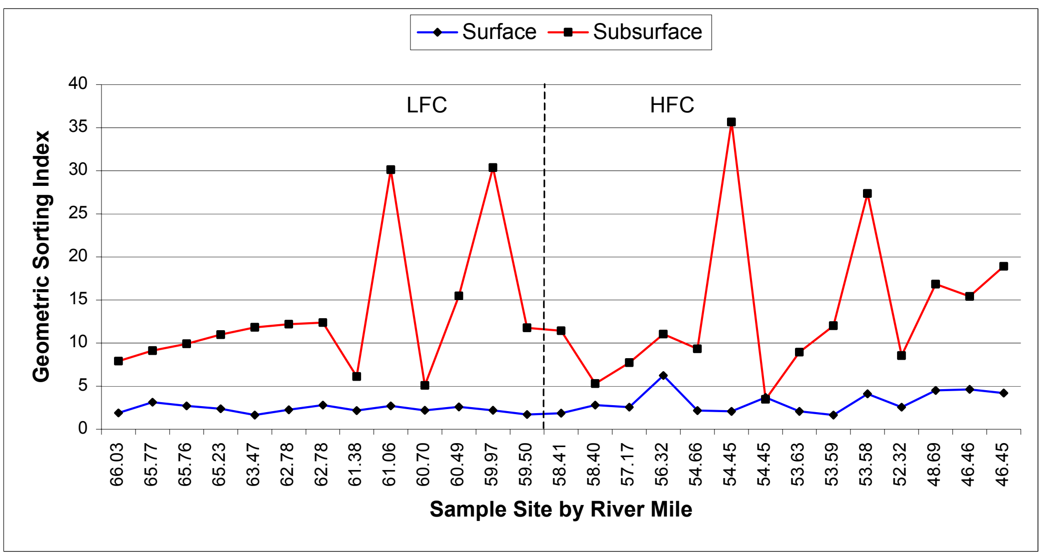

Figure 5.2-7. Geometric sorting index values (sg) by sample location, sample stratum, and reach (LFC, HFC).

5.2.5 Fine Sediment Analyses

The percentage of fine grains (referred to as fines) in bulk gravel samples that were <1 mm diameter, by riffle and reach (LFC, HFC), is shown in Figure 5.2-8 for surface samples, and Figure 5.2-9 for subsurface samples. For surface samples, the percentage of fines <1 mm diameter in bulk gravel samples were below the 14 percent suitability threshold at all riffles sampled in both reaches. The percentage of fines <1 mm diameter in bulk gravel surface samples generally were highest in riffles in the HFC, and the percentage of fines <1 mm diameter in bulk gravel surface samples generally increased with distance downstream. For subsurface samples, the percentage of fines <1 mm diameter in bulk gravel samples were below the 14 percent suitability threshold at all riffles sampled in the LFC, and at 86 percent of riffles sampled in the HFC. The percentage of fines <1 mm diameter in bulk gravel subsurface samples generally were highest in riffles in the HFC, and the percentage of fines <1 mm diameter in bulk gravel subsurface samples generally increased with distance downstream.

The percentage of fines in bulk gravel samples that were <3 mm diameter, by riffle and reach (LFC, HFC), is shown in Figure 5.2-10 for surface samples, and Figure 5.2-11 for subsurface samples. For surface samples, the percentage of fines <3 mm diameter in bulk gravel samples was below the 30 percent suitability threshold at all riffles sampled in both reaches. The percentage of fines <3 mm diameter in bulk gravel surface samples generally was highest in riffles in the HFC, and the percentage of fines <3 mm diameter in bulk gravel surface samples generally increased with distance downstream. For subsurface samples, the percentage of fines <3 mm diameter in bulk gravel samples was below the 30 percent suitability threshold at all riffles sampled in the LFC, and at 93 percent of riffles sampled in the HFC. The percentage of fines <3 mm diameter in bulk gravel subsurface samples generally was similar between the LFC and the HFC. Spatial trends were not evident.

The percentage of fines in bulk gravel samples that was <6 mm diameter, by riffle and reach (LFC, HFC), is shown in Figure 5.2-12 for surface samples, and Figure 5.2-13 for subsurface samples. For surface samples, the percentage of fines <6 mm diameter in bulk gravel samples was below the 30 percent suitability threshold at all riffles sampled in both reaches. The percentage of fines <6 mm diameter in bulk gravel surface samples generally was highest in riffles in the HFC, and the percentage of fines <6 mm diameter in bulk gravel surface samples generally increased with distance downstream. For subsurface samples, the percentage of fines <6 mm diameter in bulk gravel samples was below the 30 percent suitability threshold at 92 percent of riffles sampled in the LFC, and at 79 percent of riffles sampled in the HFC. The percentage of fines <3 mm diameter in bulk gravel subsurface samples generally was similar between the LFC and the HFC. Spatial trends were not evident.

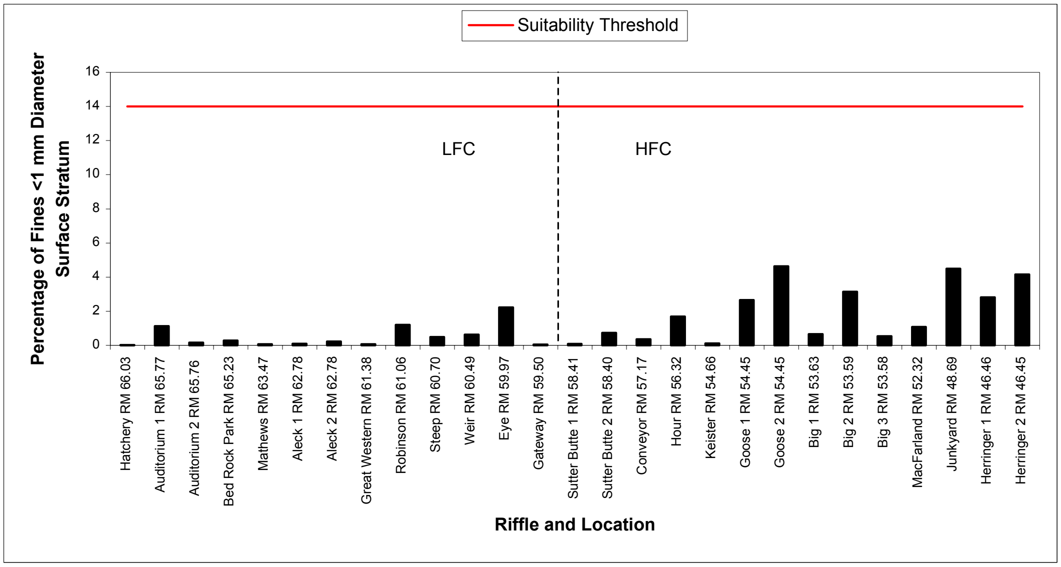

Figure 5.2-8. The percentage of fine grains, by riffle and reach (LFC, HFC), that were <1 mm diameter in surface bulk gravel samples.

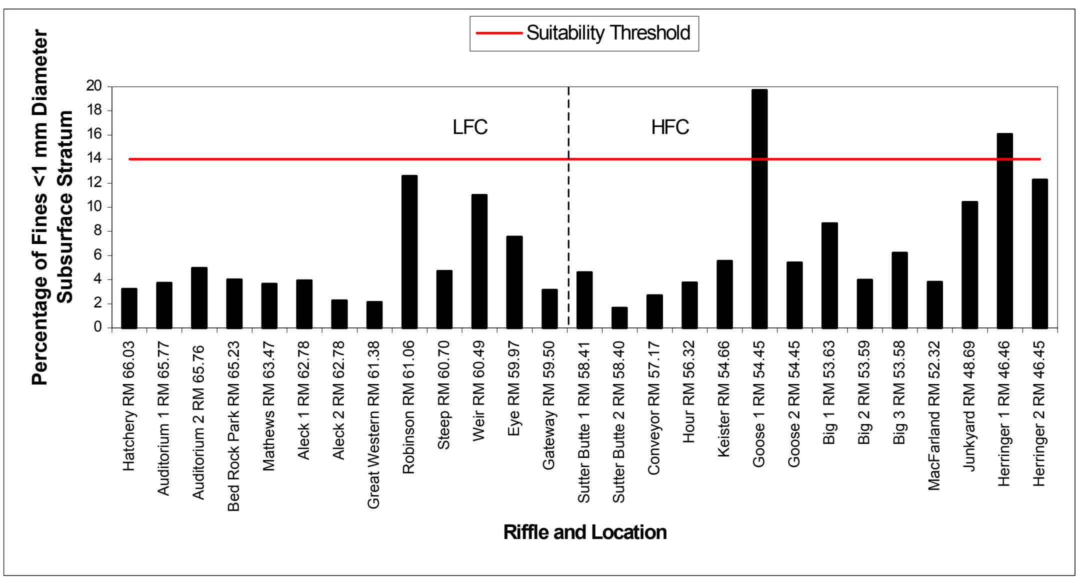

Figure 5.2-9. The percentage of fine grains, by riffle and reach (LFC, HFC), that were <1 mm diameter in subsurface bulk gravel samples.

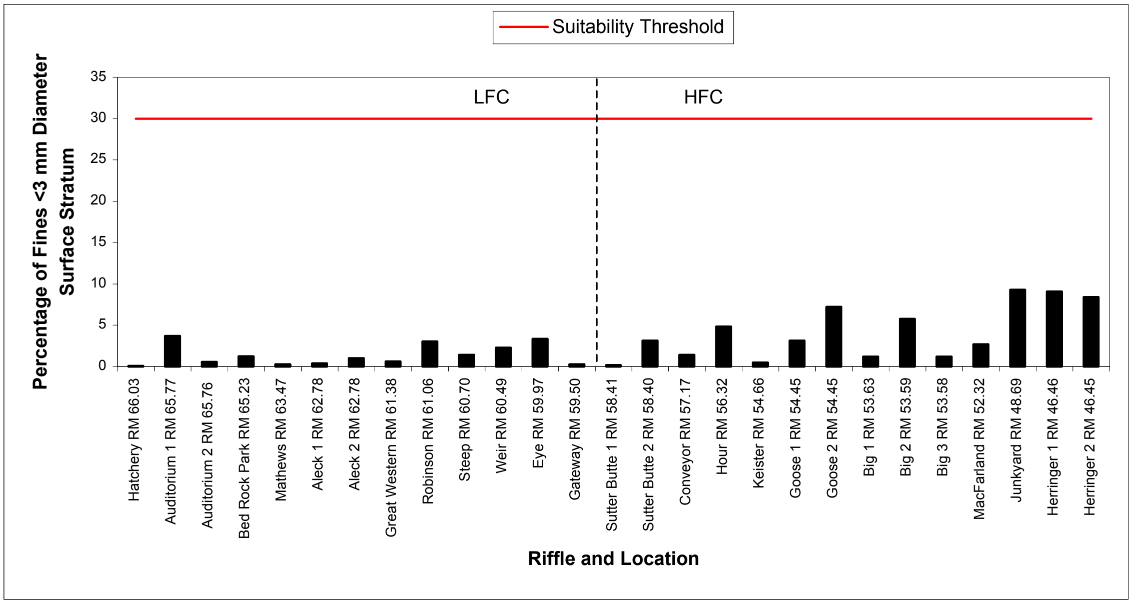

Figure 5.2-10. The percentage of fine grains, by riffle and reach (LFC, HFC), that were <3 mm diameter in surface bulk gravel samples.

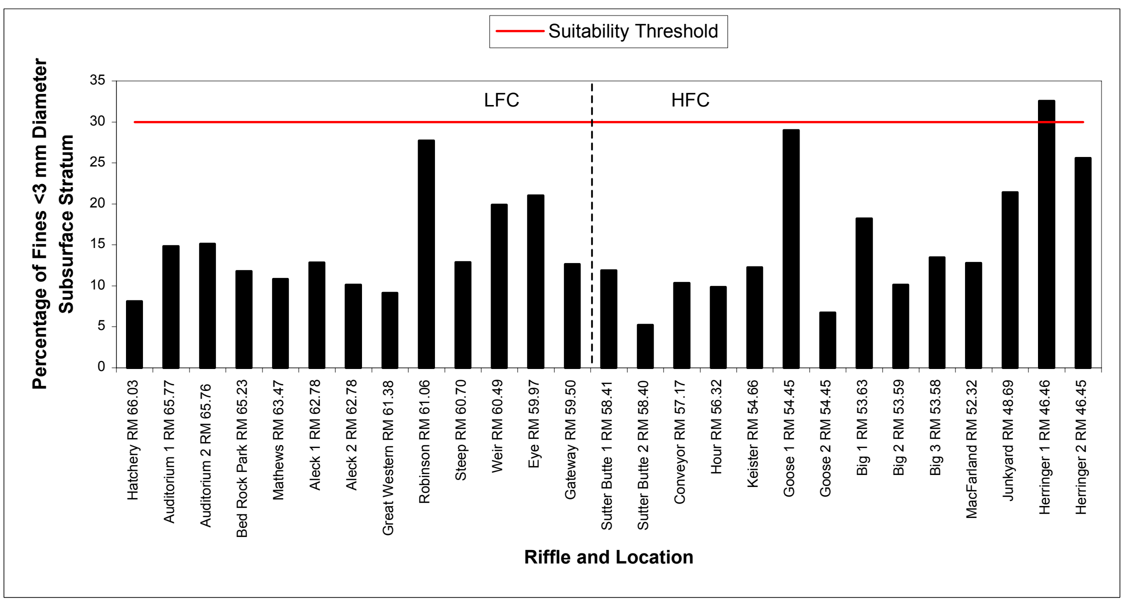

Figure 5.2-11. The percentage of fine grains, by riffle and reach (LFC, HFC), that were <3 mm diameter in subsurface bulk gravel samples.

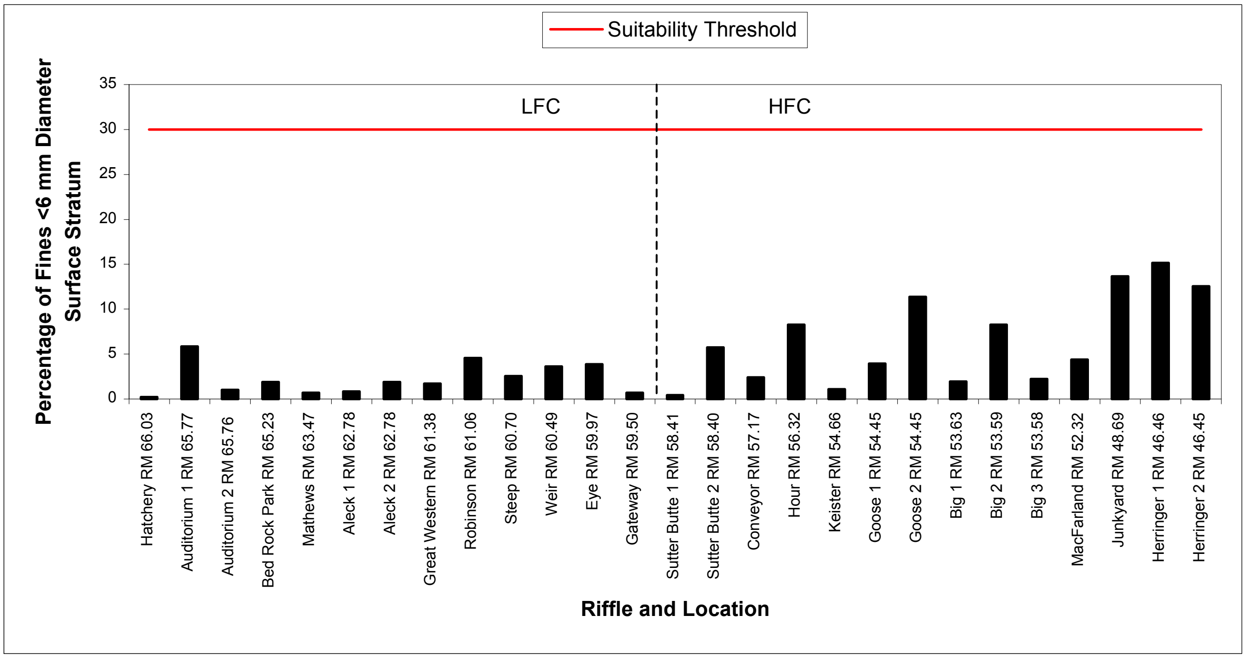

Figure 5.2-12. The percentage of fine grains, by riffle and reach (LFC, HFC), that were <6 mm diameter in surface bulk gravel samples.

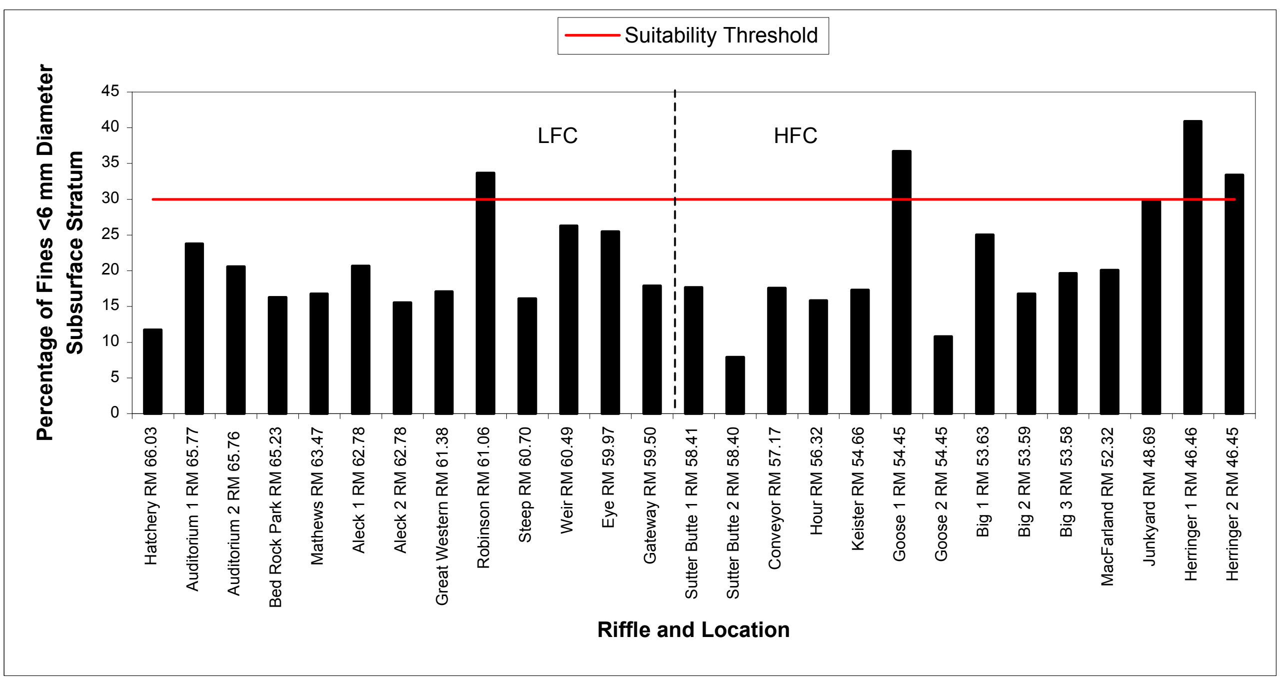

Figure 5.2-13. The percentage of fine grains, by riffle and reach (LFC, HFC), that were <6 mm diameter in subsurface bulk gravel samples.

6.0 ANALYSES

6.1 EXISTING CONDITIONS/ENVIRONMENTAL SETTING

Task 2A is a subtask of SP-F10, *Evaluation of Project Effects on Salmonids and their Habitat in the Feather River Below the Fish Barrier Dam.* Task 2A fulfills a portion of the FERC application requirements by evaluating substrate suitability for the spawning and embryo incubation life stage of Chinook salmon and Steelhead in the lower Feather River.

6.1.1. Other Studies and Data Sets

Gravel availability limits salmon production through a complex interaction of spawning distribution, redd superimposition, and the duration of spawning (EA Engineering Science and Technology 1992). Available spawning areas are influenced by streamflow, gravel armoring, vegetative encroachment, and site-specific flow characteristics (EA Engineering Science and Technology 1992). Numerous field studies have been conducted in the Feather River to assess gravel substrate. Warner (1954) conducted observational surveys in the lower Feather River on gravel substrate in a two mile long reach below Sutter Butte Dam (this dam no longer exists), and concluded that optimal spawning gravel utilization would occur under a sustained flow of 800 cfs. The sampling was purely observational, and literature was not cited regarding the gravel quality rating system used.

Painter (1975) measured gravel quality in the lower Feather River at four riffles (RM 64.5, RM 56.5, RM 54.5 and RM 46) using bulk sample and intragravel techniques. Results of the bulk sample analyses showed a gradual deterioration of gravel quality with distance downstream of the Oroville Dam. However, the study concluded that the construction of Oroville Dam did not deteriorate gravel quality conditions in the lower Feather River, gravel conditions were good for the natural propagation of Chinook salmon, and that egg survival was very low in the LFC due to overcrowding and redd superimposition.

DWR (1982) conducted surface pebble counts and bulk gravel samples in the lower Feather River and concluded that riffles in the LFC were becoming armored with gravel too coarse for spawning. The magnitude of armoring decreased with downstream distance, and reportedly was due to reduced gradient and availability of gravel, sand, and silt in the stream banks and channel.

DWR (1996) evaluated the quality of spawning gravels in the lower Feather River based on bulk gravel samples and Wolman surface samples obtained in the spring of 1996. The study concluded that the worst scoured areas had an armored surface layer too coarse for spawning salmonids, intragravel permeability was moderate to high, and fine sediment levels were not in amounts large enough to adversely affect egg to alevin survival through emergence. Below the Highway 162 bridge, the armoring effect diminished rapidly, and gravels in riffles generally were appropriate for salmonid spawning. Potentially harmful scouring flows (monthly peak flows) during the months of November and December (before juvenile salmonids emerge from the gravels) occurred in only two years out of a possible fifteen years examined (from 1982 to 1996). Gravel placement for restoration made comparisons difficult between the 1996 and 1982 gravel studies. DWR (1996) concluded, however, that there was a continued coarsening of the gravel in the upper five riffles of the study reach, and a reinfused load of mixed-size movable gravel in the middle section of the study reach with possible risk of fines being deposited there. Below the Afterbay river outlet, data suggested that most riffles contained gravels suitable for spawning salmonids.

Sommer et al. (2001) reported a temporal increase in salmonid spawning use in the LFC of the lower Feather River, and a temporal decrease in salmonid spawning use in the HFC of the lower Feather River. Sommer et al. (2001) stated that (using data from DWR 1982 and DWR 1996) gravel in the LFC had become progressively armored over the past 16 years, whereas gravel size distribution in the HFC had not changed detectably. Therefore, the study concluded that substrate composition did not explain trends in spawning distributions in the lower Feather River.

The analyses conducted for this report, SP-F10 Task 2A, were based on intragravel sampling (permeability, dissolved oxygen concentration, water temperature, and the upwelling and downwelling potential) and bulk gravel sampling (surface and subsurface strata). Intragravel sampling was conducted in the lower Feather River from August 6, 2003 through November 13, 2003. Bulk gravel samples were collected in the lower Feather River from October 2, 2002 through September 18, 2003. Substrate suitability for the spawning and embryo life stage of Chinook salmon and steelhead was assessed separately for each intragravel variable. The analyses for the bulk gravel samples consisted of a coarse gravel component and a fine gravel component. The primary objective of the coarse gravel suitability assessment was to determine the suitability of substrates for successful redd construction. The primary objective of the fine gravel (defined as gravels having a diameter < 6 mm diameter) suitability assessment was to determine the suitability of substrates for incubating embryos through emergence.

6.2 PROJECT RELATED EFFECTS

6.2.1 Intragravel Sampling

6.2.1.1 Permeability

Permeability can be defined as the rate at which a substrate can pass water, and the rate is influenced by substrate composition, compaction, and water viscosity (which is influenced by water temperature). Intragravel permeability (cm/hr) was measured at many sites in the lower Feather River, and was used as an indictor of gravel suitability for the spawning and embryo incubation life stage of Chinook salmon and steelhead. Incubating embryos (eggs and alevins) require adequate intragravel water flows to deliver dissolved oxygen and remove metabolic waste. Embryos may asphyxiate when intragravel water flow is not adequate. Permeability is a good indicator of the potential amount of dissolved oxygen available to incubating embryos (Terhune 1958), and thus is a standard metric used to assess the suitability of gravels for incubating embryos. However, the suitability of gravels for incubating embryos is a complex interaction of multiple variables, and permeability should not be used as a sole means of evaluating substrate suitability.

Several studies have reported observed permeability values, however, studies elucidating a range of suitable permeability values were absent from available literature. In Oregon, Coble (1961) measured permeability approximately 10 inches below the gravel surface within artificially constructed redds, and reported mean values between 8,000 cm/hr and 40,000 cm/hr. McNeil and Ahnell (1964) gathered permeability data in Alaskan streams utilized for spawning by pink salmon. The main purpose of this study was to correlate the amount of fine sediment in gravels to gravel permeability. Permeability ranged from a low of 1,260 cm/hr to a high of 33,360 cm/hr, and averaged 11,640 cm/hr. Permeability was high when gravels had less than 5 percent sands and silts that passed through a 0.83 mm sieve, and was relatively low when fine sediments made up more than 15 percent of gravel samples. Chapman (1988) measured permeability within egg pockets of Chinook salmon redds and reported a median value of 10,500 cm/hr and a range of 3,700 cm/hr to 18,000 cm/hr. Permeability also was measured in a zone of heavy spawning and in a zone of light spawning. The heavy spawning area had a median permeability of 1,300 cm/hr (range of 180 cm/hr to 3,000 cm/hr), and the light spawning area had a median permeability of 395 cm/hr (range of 190 cm/hr to 400 cm/hr). In the lower American River, Vyverberg et al. (1997) attempted to differentiate habitat used for spawning from apparently suitable habitat that remained unused based on many variables. Permeability varied significantly as a function of spawning use but not habitat type, and was the only variable measured that distinguished high from low use spawning areas. Permeability ranged from a low of 74 cm/hr to a high of 15,600 cm/hr, and averaged 4,970 cm/hr. Reiser and Bjornn (1979) presented general guidelines for incubation of salmonid embryos, and suggested, based on McNeil and Ahnell (1964), that intragravel permeability should exceed 300 cm/hr.

The permeability values presented in available literature, and the values from this study, are not directly comparable due to differences in study design (i.e., measuring at different depths within gravels, standardizing to different water temperatures, etc.). However, comparison of values will still yield a general idea as to how the permeability values from the lower Feather River compare to other systems.

The permeability values reported from this study, SP-F10 Task 2A, are similar to those found in available literature, and are higher than the minimum recommended by Reiser and Bjornn (1979). Based on the available literature, it is likely that intragravel permeability rates in the lower Feather River do not limit successful incubation of Chinook salmon and steelhead embryos.

6.2.1.2 Dissolved Oxygen Concentration

The amount of dissolved oxygen available to incubating embryos is a function of multiple variables. Permeability is an important descriptor of gravel suitability because it is an indicator of the potential amount of available dissolved oxygen, and both of these parameters can compensate for each other. For example, high dissolved oxygen concentrations can compensate for low permeability, and vice versa. Permeability is dependent upon substrate composition, compaction, and water viscosity. The volume of fine sediments in spawning gravels is inversely related to the permeability of bottom gravels (McNeil 1964). Thus, sediment conditions can have a significant effect on dissolved oxygen concentrations within gravels by restricting intragravel flow. In addition, dissolved oxygen concentrations are highly correlated with water temperature, with colder water retaining higher concentrations of dissolved oxygen. Delineating a suitable range of dissolved oxygen concentrations for incubating salmonid embryos is difficult due to the connectivity and interdependency of variables. Therefore, the suitability assessment based solely on dissolved oxygen concentrations should be interpreted carefully.

High rates of mortality can be associated with low oxygen concentrations (reportedly less than 5 ppm) (Gangmark and Bakkala 1960). Reduction in dissolved oxygen concentrations below saturation probably reduces embryo survival (Chapman 1988). Minimum concentrations of dissolved oxygen required for salmonid survival vary with changes in other variables, but reportedly generally fall between 2 mg/l and 8 mg/l (Kondolf 2000).

Chinook salmon embryos held at a water temperature of 51.8^{o}F (11^{o}C) and an oxygen concentration of 1.6 mg/l suffered 100 percent mortality (Silver et al. 1963). Eddy (1971) tested the survival of Chinook salmon embryos at various concentrations of dissolved oxygen and water temperatures. Percent survival decreased with a decrease in dissolved oxygen concentrations at all water temperatures tested, and there was a negative correlation between survival and water temperature. At all dissolved oxygen concentrations tested (3.5 mg/l, 5.0 mg/l, 7.3 mg/l, and 10.5 mg/l), survival of embryos exceeded approximately 80 percent at water temperatures of 50.9^{o}F (10.5^{o}C) and 53.6^{o}F (12^{o}C). The first large difference in embryo survival among water temperatures and among dissolved oxygen concentrations occurred between 53.6^{o}F (12^{o}C) and 56.3^{o}F (13.5^{o}C). The percentage of survival among water temperatures differed to a much greater degree than the percentage of survival within water temperature and among dissolved oxygen concentrations, suggesting that water temperature affects embryo survival more than dissolved oxygen concentrations. The results from Eddy (1971) illustrate the connectivity among environmental variables and embryo survival suggesting that 1) a significant decrease in embryo survival occurs somewhere between 53.6°F (12°C) and 56.3°F (13.5°C) regardless of dissolved oxygen concentrations, and 2) embryo survival is positively correlated with dissolved oxygen concentrations. Davis (1975) reviewed numerous studies on dissolved oxygen concentration requirements of fish and reported a mean threshold of incipient oxygen response at 8.1 mg/l for salmonid embryos. A threshold minimum (one standard deviation below the mean incipient level) of 6.44 mg/l was suggested for salmonid embryos (Davis 1975). Raleigh et al. (1986) concluded, based on a review of available literature, that the lower limit of dissolved oxygen concentration for survival of Chinook salmon embryos with short term exposures is $\geq$2.5 mg/l at water temperatures less than or equal to 44.6°F (7°C). Raleigh et al. (1986) suggested that for Chinook salmon embryo survival, at water temperatures between 44.6°F (7°C) and 50°F (10°C), dissolved oxygen concentrations should be $\geq$8 mg/l, and at water temperatures >50°F (10°C), dissolved oxygen concentrations should be $\geq$12 mg/l. Based on laboratory studies of Chinook salmon, survival from embryo to fry reportedly is highest at dissolved oxygen concentrations of 10.5 mg/l, and lowest at 3.5 mg/l for all water temperatures tested including 50.9°F (10.5°C), 53.6°F (12°C), 56.3°F (13.5°C), and 59°F (15°C) (Raleigh et al. 1986).

Few studies have explored the relationship between dissolved oxygen concentration and incubating steelhead embryos. Shumway et al. (1964) conducted experiments on steelhead egg incubation with variations in dissolved oxygen concentrations and water velocity. The study concluded that even at the highest water velocity tested, a reduction in dissolved oxygen concentration to a level below 6.6 mg/l would have resulted in a reduction of the weight of newly hatched fry. Also, steelhead incubation was affected to a greater degree by dissolved oxygen concentrations than by water velocity. Silver et al. (1963) reported that complete mortality of steelhead embryos occurred at dissolved oxygen concentrations of 1.6 mg/l, whereas a 78 percent to 85 percent hatching success occurred at dissolved oxygen concentrations of 2.6 mg/l.

Due to the lack of available information pertaining to the effects from dissolved oxygen concentrations to incubating steelhead embryos, it was assumed that the suitable range of dissolved oxygen concentrations for incubating embryos is similar for both Chinook salmon and steelhead.

The intragravel permeability in the lower Feather River appeared to be high enough to deliver appropriate amounts of dissolved oxygen to incubating embryos, assuming suitable dissolved oxygen concentrations exist within the water. Based on available literature and excluding interaction with other variables, intragravel dissolved oxygen concentrations in the lower Feather River generally are within suitable ranges. However, the influence from water temperatures may affect the suitability of dissolved oxygen concentrations.

The water temperature data collected during the intragravel sampling showed that intragravel water temperatures (down to a gravel depth of 18 inches) were below 56°F

(13.3°C) from September 10, 2003 through November 13, 2003. Based on available literature, the combination of intragravel dissolved oxygen concentrations and intragravel water temperatures appears to have been suitable for incubating Chinook salmon and steelhead embryos from September 10, 2003 through November 13, 2003. Intragravel water temperatures (down to a gravel depth of 18 inches) generally exceeded 62°F (16.7°C) from August 6, 2003 through August 19, 2003. Based on available literature, the combination of intragravel dissolved oxygen concentrations and intragravel water temperatures appears to have been unsuitable for incubating Chinook salmon and steelhead embryos from August 6, 2003 through August 19, 2003. Reportedly, few incubating salmonid embryos are present in the lower Feather River during this time period (DWR 2004b). The Chinook salmon spawning and embryo incubation life stage reportedly occurs in the lower Feather River from August 15 through February 15 (DWR 2004c). The steelhead spawning and embryo incubation life stage reportedly occurs in the lower Feather River from December through May (DWR 2003a; Moyle 2002). Therefore, the effects to incubating salmonid embryos from high water temperature during August 6, 2003 through August 19, 2003 may have been insignificant.

The water temperature data collected during the intragravel sampling efforts are single data points, not time series data, and do not represent potentially occurring temporal variation. The data also were collected on different days during different times of the day. Therefore, the water temperature data collected during the intragravel sampling may not be good indicators of substrate suitability as it relates to incubating Chinook salmon and steelhead embryos. Water temperature time series data are available for the lower Feather River. The data represent mean daily water temperatures within the water column of the lower Feather River. The relationship between water column temperatures and intragravel water temperatures is not known for the lower Feather River. Therefore, the time series data were not used to evaluate the suitability of intragravel water temperatures and the associated effects to dissolved oxygen concentrations and incubating salmonid embryos.

6.2.1.3 Water Temperature

Intragravel water temperature can affect incubating embryos through direct exposure, or indirectly by influencing the amount of dissolved oxygen retained by water. Effects from the interaction between intragravel water temperature and dissolved oxygen concentration was discussed in Section 6.2.1.2. The discussion in this section will be restricted to the effects from direct exposure during the time period that Chinook salmon and steelhead embryos are present within gravels in the lower Feather River.

The Chinook salmon spawning and embryo incubation life stage reportedly occurs in the lower Feather River from August 15 through February 15 (DWR 2004c). The water temperature data collected during the intragravel sampling showed that intragravel water temperatures (down to a gravel depth of 18 inches) were below 56°F (13.3°C) from September 10, 2003 through November 13, 2003 (Figure 6.2-1). Agreement exists within available literature and regulatory documents that water temperatures below 56°F (13.3°C) are suitable for incubating Chinook salmon embryos (see Section 2.1.2.1). Therefore, intragravel water temperatures in the lower Feather River likely were suitable for incubating Chinook salmon embryos from September 10, 2003 through November 13, 2003 (down to a gravel depth of 18 inches). The water temperature data collected during the intragravel sampling showed that intragravel water temperatures (down to a gravel depth of 18 inches) generally exceeded 62°F (16.7°C) from August 15, 2003 through August 19, 2003 (Figure 6.2-1). Based on available literature and regulatory documents, harmful effects to incubating Chinook salmon embryos may have occurred from August 15, 2003 through August 19, 2003. A discussion of the biological effects to incubating Chinook salmon embryos associated with exposure to water temperatures exceeding 62°F (16.7°C) is provided in Section 2.1.2.1. Intragravel water temperature data were not collected from August 16, 2003, through September 9, 2003, and the suitability of intragravel water temperatures during this time period was uncertain.

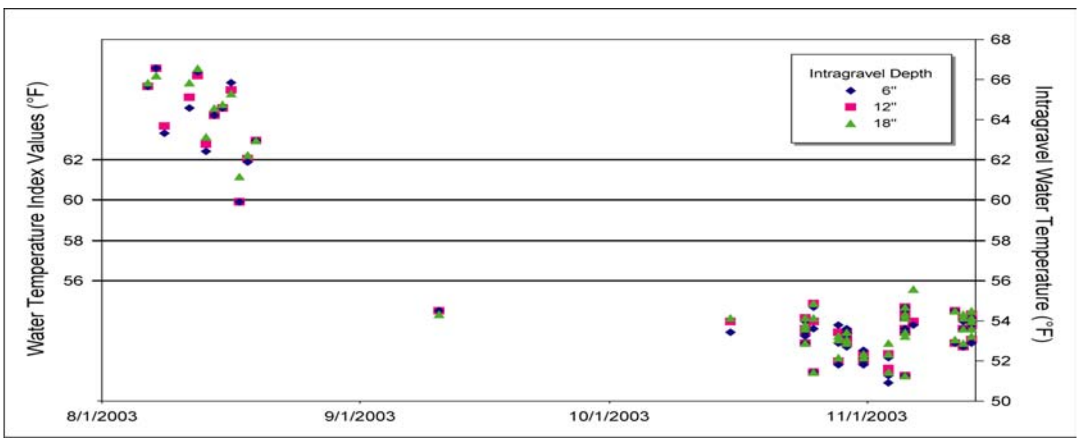

Figure 6.2-1. Intragravel water temperatures by sample depth, and associated water temperature index values.

The steelhead spawning and embryo incubation life stage reportedly occurs in the lower Feather River from December through May (DWR 2003a; Moyle 2002). Intragravel water temperature data were not collected from December through May. Therefore, a discussion of intragravel water temperature and the effects to incubating steelhead embryos is not provided.

6.2.1.4 Upwelling and Downwelling Potential

The general theory among fisheries biologists is that salmonids prefer to spawn in transitional areas between pools and riffles (Bjornn and Reiser 1991), with spawning activity concentrated in the upstream segments of riffles. Studies have demonstrated the presence of upwelling and downwelling currents, also known as the vertical hydraulic gradient, in these transitional areas (Bjornn and Reiser 1991). Water generally upwells where permeability and/or depth of gravel decreases in the direction of streamflow, and where the longitudinal bed profile is concave (Vaux 1968). The downstream interface between a riffle and a pool is typical of such characteristics. Water generally downwells where permeability and/or depth of gravel increases in the direction of streamflow, and where the longitudinal bed profile is convex (Vaux 1968). The upstream interface between a riffle and a pool is typical of such characteristics. Mesick (2001) stated that downwelling occurs upstream from surface flow obstacles, such as the crest of a riffle, and that upwelling occurs in areas downstream from flow obstacles, particularly at the tails of riffles. The general belief is that dissolved oxygen concentrations are higher in downwelling currents because of the biological consumption of dissolved oxygen within intragravel substrates (i.e., consumption of oxygen by eggs and alevins). Therefore, it is thought that spawning site selection by salmonids is associated with downwelling currents because of the advantage of higher dissolved oxygen concentrations, and that typically such areas exist at the head of riffles.

Several studies have noted the relationship between spawning areas and the vertical hydraulic gradient. Contradictory results have been reported. Chinook salmon spawning sites in the Kamchatka River, Russia were located in places where downwelling currents were strongest in connection with distinctive features of the microrelief, such as those areas at the boundary where a pool gives way to a rapid (Vronskiy 1972). Lorenz and Eiler (1989) examined spawning habitat and redd characteristics of sockeye salmon in Alaska and reported that upwelling current was detected in nearly 60 percent of the sites sampled. The sites with upwelling currents had lower water velocities and more variable substrate compositions than sites without upwelling currents. Geist and Dauble (1998) reviewed available literature on intragravel flow in relation to salmon spawning habitat and stated that most studies suggest that upwelling areas are more important than downwelling areas for Chinook salmon spawning. However, recent research (Vronskii and Leman 1991) suggests that intragravel flow, regardless of the direction of the vertical hydraulic gradient, is the critical variable associated with spawning habitat.

In the lower Feather River, generally there were no discernible trends in vertical hydraulic gradient within Chinook salmon redds, either by reach or by study area. Statistical differences were not detected in vertical hydraulic gradient between the LFC and the HFC. When data were pooled (LFC and HFC), differences were slight. For example, upwelling currents were detected at 50 percent of the sites sampled within Chinook salmon redds (36 percent downwelling, and 14 percent neutral). Upwelling currents were detected at a higher frequency within Chinook salmon redds at 12 inch and 18 inch sample depths than at 6 inch sample depths. At a depth of 6 inches within Chinook salmon redds, upwelling currents were detected at 38 percent of sample sites (41 percent downwelling, and 21 percent neutral). The intragravel data suggest that the direction of the vertical hydraulic gradient (i.e., whether there is upwelling or downwelling) is not a discriminating factor in spawning site selection by Chinook salmon in the lower Feather River. The data also suggest that the direction of the vertical hydraulic gradient is not a discriminating factor in spawning site selection between the LFC and HFC. However, of note is that upwelling or downwelling currents were detected in 86 percent of the samples within Chinook salmon redds, suggesting that intragravel flow, regardless of the direction of the vertical hydraulic gradient, is an influential variable associated with spawning site selection by Chinook salmon in the lower Feather River. The high permeability (Section 6.2.1.1) and the high dissolved oxygen concentrations (Section 6.2.1.2) within gravels in the lower Feather River may compensate for any disadvantages associated with spawning in gravels that do not have downwelling currents.

The general theory among fisheries biologists is that salmonids prefer to spawn in transitional areas between pools and riffles (Bjornn and Reiser 1991), with spawning activity concentrated in the upstream segments of riffles. In the lower Feather River, there were no discernible trends in vertical hydraulic gradient among riffle sections within Chinook salmon redds. However, upwelling currents were detected at a higher frequency than downwelling currents within Chinook salmon redds in each of the riffle sections sampled (66 percent top, 66 percent middle, and 52 percent bottom). The frequency at which each current type (upwelling, downwelling, and neutral) was detected remained consistent among riffle sections. Therefore, geomorphic features, and the resulting vertical hydraulic gradient, may not be a discriminating factor in the spatial component associated with spawning site selection by Chinook salmon.

Redd construction results in negligible currents in the pit (facilitating egg deposition), and increased currents over and through (downwelling) the tailspill of a redd (Bjornn and Reiser 1991). Egg covering activity results in the formation of a second pit upstream, which also may be used for spawning. Increased permeability and the convexity of the tailspill substrate induces downwelling of water into the gravel, creating a current past eggs. The current brings oxygen to the eggs and removes metabolic wastes. The shape of salmonid redds, by design, induces downwelling. The results from this study are surprising in that downwelling currents were not detected at higher frequencies upstream from the tailspill in Chinook salmon redds (the location of data collection) because this is the location downwelling would be expected to occur (see Figure 4.7 in Bjornn and Reiser 1991). A possible explanation for this is that sample riffles were chosen on the basis of degree of spawning activity, and spawning activity within sampled riffles was extremely high. The rate of superimposition in the lower Feather River is considered high (DWR 2004c; Sommer et al. 2001), with redds being superimposed multiple times. The structure and shape of Chinook salmon redds in the lower Feather River may deviate from that of a normal redd because of the continual disturbance activity from spawning salmon. The resulting structure and shape of the disturbed redds may not induce downwelling currents. Also, the level of spawning activity, in association with high superimposition, made it very difficult to identify Chinook salmon redds, discern the boundaries between Chinook salmon redds, and identify specific structures within each Chinook salmon redd. The possibility exists that the standpipe was driven into an area of the redd, such as the pit, where downwelling currents typically do not occur.

Intragravel data were collected within Chinook salmon redds and not within steelhead redds. Data also were collected outside of the time period during which steelhead spawn in the lower Feather River. The discussion associated with vertical hydraulic gradient did not include steelhead redds because it is uncertain if intragravel flows have temporal variation. Therefore, assuming that the same data set would apply to steelhead redds would not be prudent.

6.2.1.5 Egg Pocket and Alevin Depth Within Gravel Substrates

Intragravel variables can vary with gravel depth. Determining the depth within gravels that incubating embryos typically are located was necessary for a thorough suitability assessment of intragravel variables. Anecdotal information describing intragravel depths of incubating embryos was present in available literature, but few studies have rigorously explored this variable. Salmonids reportedly deposit eggs to a depth of 3 inches (7.62 cm) to 15 inches (38.10 cm) within gravel substrates (McNeil and Ahnell 1964; Terhune 1958). Bjornn and Reiser (1991) expanded upon general information and stated that large fish, such as Chinook salmon, may dig as deep as 16.9 inches (43 cm) below the streambed surface, but average egg pocket depths are in the 7.9 inch (20 cm) to 11.8 inch (30 cm) range. Montgomery et al. (1996) measured egg pocket depth within 40 chum salmon redds in Washington and Alaska, and reported a range from 3.9 inches (9.8 cm) to 19.3 inches (48.9 cm), with a mean depth of 8.9 inches (22.6 cm). Evenson (2001) measured egg pocket depth within 28 Chinook salmon redds in the Trinity River, California, and reported a range from 5.9 inches (15 cm) to 20.9 inches (53 cm), with a mean depth of 13.4 inches (34 cm).

Chinook salmon are the largest species of salmon present in North America. Steen and Quinn (1999) reported a positive relationship between female size and egg burial depth of sockeye salmon, and this relationship likely is universal among salmonid species. Based on the range of depths outlined above, it is likely that Chinook salmon in the lower Feather River deposit eggs throughout the intragravel stratum at least to a depth of 18 inches (the deepest depth sampled during the intragravel sampling). Therefore, it is important to assess intragravel suitability to incubating embryos for all depths sampled in this study. Information pertaining to the range of gravel depths utilized by alevins is unavailable, but it was assumed that alevins utilize gravel depths to at least 18 inches.

Variation existed among sample depths for all intragravel variables measured (permeability, dissolved oxygen concentration, water temperature, and upwelling and downwelling potential), and statistical differences existed among sample depths for all intragravel variables tested (water temperature was not tested for differences among sample depth). However, for each intragravel variable and at each sample depth, values were within the range of suitability reported in available literature and agency documents. The exceptions were intragravel water temperatures from August 6, 2003 through August 19, 2003. During this time period, intragravel water temperatures were characterized as unsuitable for incubating Chinook salmon and steelhead embryos. Few incubating salmonid embryos are present in the lower Feather River during this time period (DWR 2004b). Therefore, the effects to incubating salmonid embryos from high water temperature during August 6, 2003 through August 19, 2003 may have been insignificant.

Intragravel permeability, dissolved oxygen concentration, water temperature, and upwelling and downwelling potential, during the time period that data were collected, likely did not limit survival of incubating Chinook salmon and steelhead embryos in the lower Feather River.

6.2.2 Bulk Gravel Sampling

Bulk gravel samples were collected in the lower Feather River to assess the suitability of gravel size distributions for the spawning and embryo incubation life stage of Chinook salmon and steelhead. Gravel suitability differs for redd construction, embryo incubation, and emergence. For example, female salmon and steelhead must be able to move gravels to successfully construct redds. During embryo incubation, gravels must be sufficiently free of fine sediment such that water flow delivers adequate amounts of dissolved oxygen. After hatching, alevins life in interstitial spaces within gravels prior to emergence and porosity must allow intragravel movement. Fine sediment can create movement barriers and limit successful embryo incubation. The upper range of suitable gravel size distributions is a function of female body length, and the lower range of suitable grave size distributions is a function of tolerable levels of fine sediment during embryo incubation. The discussion for the gravel size distribution suitability assessment is split into two components. The coarse gravel assessment addresses if gravels are suitable for redd construction. The fine gravel assessment addresses if the level of intragravel fine sediment is suitable for incubating embryos.

6.2.2.1 Coarse Gravel Assessment

The suitability of gravels across all gravel sizes was evaluated using a range of suitable gravel size distributions (suitability curves) estimated from Vyverberg et al. (1997). Spawning females must be able to move gravels for successful redd construction. Available spawning habitat is reduced when gravels are too coarse for female Chinook salmon and steelhead to move which causes superimposition, reduced embryo survival, and an overall decrease in productivity. The upper limit of suitability for spawning is defined by the largest females because larger individuals can move larger gravels (Kondolf and Wolman 1993). Based on carcass survey data from 2000 through 2003, the average length of female Chinook salmon in the lower Feather River was 83.5 cm

(32.9 inches), and the first and third quartiles were 78 cm (30.7 inches) and 90 cm (35.4 inches), respectively. Kondolf and Wolman (1993) developed a relationship between fish length and suitable gravel sizes for spawning salmon. The study concluded that generally salmonids can spawn in gravels with a median diameter up to about 10 percent of their body length. Based on this relationship, the median diameter (D_{50}) of the upper limit of gravel sizes that Chinook salmon in the lower Feather River likely can move is 83.5 mm (3.3 inches), with a first and third quartile range between 78 mm (3.1 inches) and 90 mm (3.5 inches). The suitability curves estimated from Vyverberg et al. (1997) generally agree with the calculated largest median diameter gravels that Chinook salmon in the lower Feather River likely can move during redd construction. Data were not available for steelhead spawning female lengths in the lower Feather River, but it is likely that the upper range of suitable gravel diameters for steelhead have a smaller median gravel diameter than those for Chinook salmon. In the LFC, 23 percent of surface sample gravel size distributions were characterized as suitable, and 100 percent of subsurface sample gravel size distributions were characterized as suitable. In the HFC, 79 percent of surface sample gravel size distributions were characterized as suitable, and 71 percent of subsurface sample gravel size distributions were characterized as suitable. Of note is that, when compared to the range of suitability curves, surface samples in the LFC were characterized as unsuitable generally because too many coarse gravels were present in samples (Figure 5.2-4), and that subsurface samples in the HFC were characterized as unsuitable generally because too many fine gravels were present in samples (Figure 5.2-5). Surface samples in the LFC generally are more coarse than surface samples in the HFC, and subsurface sample gravel size distributions are more similar between the LFC and HFC. The results from the gravel size distribution curve analysis suggests that the surface stratum in the LFC is becoming armored. An armored stratum can be defined as an erosion-resistant layer of relatively large particles on the surface of a streambed, typically formed by removal of finer particles through erosion (Bunt and Apt 2001). Sommer et al. (2001) compared gravel size distributions in the lower Feather River between samples gathered in 1982 and 1996. The study concluded that gravels in the LFC were becoming progressively armored through time, whereas downstream (HFC) substrate composition had not changed detectably. Armoring is typical of stream reaches directly downstream of dams. Dams effectively block downstream passage of sediments, and limit downstream recruitment of gravels (Bunt and Apt 2001). Small to medium gravels are relocated downstream by fluvial processes, and the surface layer coarsens through time due to lack of recruitment. Construction of Oroville Dam restricts downstream gravel recruitment, and may contribute to the temporal coarsening of surface substrates in the LFC.

In this study, the armor index (A) and the geometric sorting index (sg) were calculated for use as additional indicators of armoring. The armor index is an indicator of the degree of armoring, and is calculated by comparing the median gravel diameter (D_{50}) of the armored layer (surface) with the median gravel diameter of the subarmor (subsurface) layer (Bunt and Abt 2001). The armor index does not describe the coarseness of the surface layer, but rather the disparity between surface and subsurface gravel size distributions. For purposes of this report, the armor index was a good indicator of disparity between the LFC and the HFC. Armor index values between 1.5 and 3 are typical for most systems (Vyverberg et al. 1997). Armor index values were highest in the LFC (Figure 5.2-6). Average armor index values from the lower Feather River were higher than those reported for the lower American River (Vyverberg et al. 1997). The greater differences in gravel size distributions in the LFC between surface and subsurface strata lends credence to the notion that the surface layer in the LFC is coarsening. The geometric sorting index (sg) reflects how well fluvial processes have concentrated particles of similar size. Gravel deposits composed of a small range of gravel sizes are considered well-sorted and have a low sg value. Gravel deposits composed of a large range of gravel sizes are considered poorly-sorted and have a high sg value. A perfectly sorted gravel deposit has an sg value of 1, a well-sorted gravel deposit has an sg value of <2.5, an sg value of approximately 3 is considered normal, and an sg value >4.5 is poorly-sorted (Vyverberg et al. 1997). Results from this study indicate that sg values were lowest in surface samples in the LFC (2.3 average), indicating a well sorted stratum and homogenization of gravel size distribution. The results suggest that the surface layer in the LFC is composed of a small range of coarse gravel sizes (this conclusion also is based on the results from the gravel size distributions curves and the armor index values).

The results from the gravel size distribution curves, the armor index values, and the geometric sorting index values suggest that the surface stratum in the LFC primarily consists of large gravels. However, the question still remains as to whether surface gravels in the lower Feather River are too coarse for spawning fish to move for successful redd construction. Data were not available for steelhead, thus the discussion focuses on Chinook salmon. Based on carcass survey data from 2000 through 2003, the D_{50} of the upper limit of gravel sizes that Chinook salmon in the lower Feather River likely can move during redd construction is 83.5 mm (3.3 in), which was the criterion used to evaluate the suitability of gravels for redd construction. Figure 6.2-2 shows the D_{50} for each surface sample site and each reach (LFC, HFC), and the threshold for suitability. In the LFC, 78 percent of surface samples had a median gravel diameter exceeding the suitability threshold. In the HFC, 29 percent of surface sample had a median gravel diameter exceeding the suitability threshold. Figure 6.2-3 shows the D_{50} for each subsurface sample site and each reach, and the threshold for suitability. In the lower Feather River, 100 percent of subsurface samples had a median gravel diameter below the suitability threshold.

Results from gravel size distribution curves, armor index values, and the geometric sorting index suggest that surface strata in the lower Feather River are coarse, and that armoring is particularly evident in the LFC. The median gravel diameter of surface samples in the LFC suggest that gravels generally are too large for successful redd construction by Chinook salmon in the LFC. Gravel suitability for spawning Chinook salmon generally increased with distance downstream from Oroville Dam.

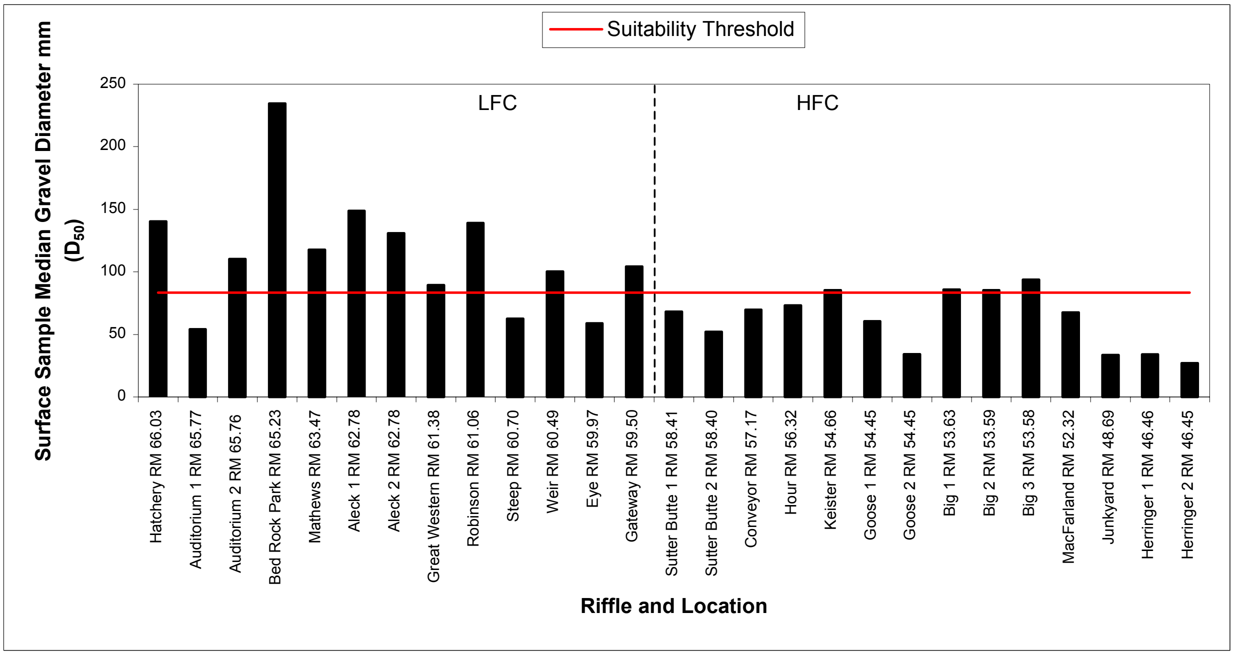

Figure 6.2-2. Surface sample median gravel diameters (D_{50}) for each sample site by reach (LFC, HFC), and the threshold for suitability.

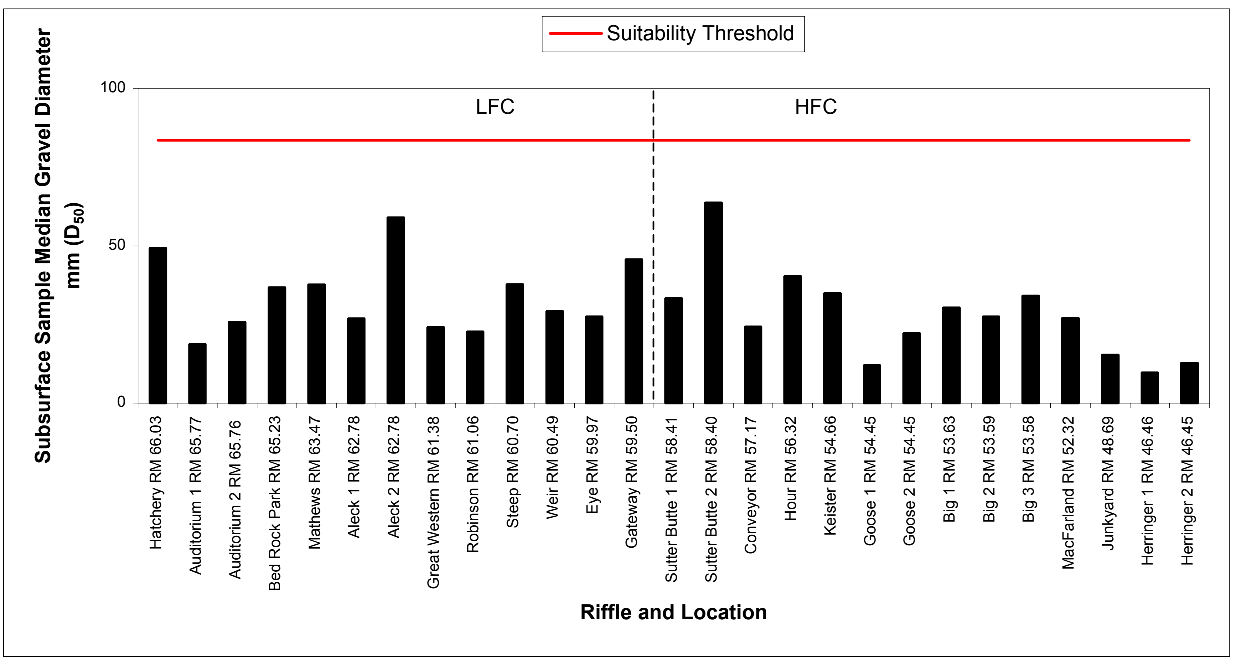

Figure 6.2-3. Subsurface sample median gravel diameters (D_{50}) for each sample site by reach (LFC, HFC), and the threshold for suitability.

6.2.2.2 Fine Gravel Assessment

Gravel must be sufficiently free of fine sediment such that the flow of water through gravels brings adequate amounts of dissolved oxygen to incubating embryos, and removes metabolic waste. Alevins living in the intragravel environment pass through interstitial spaces. High levels of fine sediments within gravels can form passage barriers leading to decreased alevin survival. The gravel requirements of salmonids differ between redd construction and embryo incubation (Kondolf 200). Studies have shown that interstitial fine sediment can reduce gravel permeability and lead to less intragravel flow, which can result in lower intragravel dissolved oxygen concentrations and suffocation of incubating embryos (Kondolf 2000). Thus, the lower limit of gravel suitability is defined by tolerable levels of fine gravels by incubating embryos.

McNeil and Ahnell (1964) explored the success of pink salmon spawning relative to the size of spawning bed materials, and reported that successful embryo incubation was inversely related to the percentage of gravels finer than 0.83 mm diameter. The study also reported that permeabilities were low where bottom materials contained more than 15 percent by volume of sands and silts passing through a 0.83 mm sieve. Based on this study, many authors accepted 0.83 mm as a biologically significant size threshold, even though 0.83 mm was an arbitrary threshold based on available sieve sizes. Kondolf (2000) suggested that rounding the 0.83 mm threshold to 1 mm was preferable for suitability assessments. Kondolf (2000) also suggested that, prior to suitability assessments, the percentage of fine sediment within gravels should be adjusted downward for probable cleansing effects occurring during redd construction. Based on a review of many studies, Kondolf (2000) concluded that 50 percent of embryos survive through emergence when the percentage of gravels finer than 1 mm diameter is approximately 14 percent.

Fine sediments can blanket or infiltrate stable gravels. A seal can form if the fine particles are large enough to bridge openings between gravel particles, which can restrict alevin emergence (Beschta and Jackson 1979). To assess whether fine sediments may impede emergence of alevins, Kondolf (2000) suggested using gravels with diameters of 3 mm and 6 mm as indicators of suitability. However, the percentages associated with 50 percent embryo survival through emergence for each gravel size was not explicitly stated. The literature review summary provided in Kondolf (2000) shows that the maximum percentage of grains finer than 3 mm and 6 mm corresponding with 50 percent embryo survival through emergence varied widely among studies. Therefore, the mean percentage of grains finer than 3 mm and 6 mm corresponding with 50 percent embryo survival in the studies reviewed in Kondolf (2000) were used as suitability thresholds (Table 1, page 268 in Kondolf 2000).

Many different methods are presented in available literature describing how to assess the suitability of fine grain components in bulk gravel samples. The procedures outlined in Kondolf (2000) were used in this report to remain consistent with methodologies used in many other studies and reports. The following criteria were used to assess the suitability of fines for the spawning and embryo incubation life stage of Chinook salmon and steelhead: 1) gravels were considered suitable if $\leq$ 14 percent of bulk gravel samples consisted of gravels with diameters <1 mm, 2) gravels were considered suitable if $\leq$30 percent of bulk gravel samples consisted of gravels with diameters <3 mm, and 3) gravels were considered suitable if $\leq$30 percent of bulk gravel samples consisted of gravels with diameters <6 mm. The 50 percent survival to emergence value is arbitrary, but is justified because redds with at least 50 percent emergence success likely would be considered as productive by most biologists (Kondolf 2000).

Based on the literature review and discussion provided in section 6.2.1.5, it is likely that Chinook salmon in the lower Feather River deposit eggs throughout the intragravel stratum at least to a depth of 18 inches (the deepest depth sampled during the intragravel sampling). Therefore, it is important to assess the suitability of fines for both the surface and subsurface stratum. Information pertaining to the range of depths utilized by alevins was unavailable, but it was assumed that alevins utilize gravel depths down to 18 inches. Female salmonids winnow fine sediment from gravels during redd construction. Gravels within redds typically contain less fine sediment than the same gravels prior to redd construction (Kondolf 2000). The reduction in fine sediment during spawning depends largely on the amount of fine sediment initially present, and reductions can transform unsuitable gravels into suitable gravels (Kondolf and Wolman 1993). Kondolf (2000) suggested adjusting the percentage of fine sediments downward when performing gravel suitability assessments to account for probable cleansing effects occurring during redd construction. The percent reduction suggested by Kondolf (2000) varied according to grain size, but was as high as 42 percent. Results from the current study suggest that the percentage of fine sediments (up to a diameter of 6 mm) within gravels (down to a depth of 18 inches) in the lower Feather River are suitable for incubating Chinook salmon and steelhead embryos. The fine sediment size distribution was characterized as unsuitable for very few samples, however, samples were not adjusted for the probable effects of cleansing during redd construction. Had all samples been adjusted, 100 percent of samples would have been characterized as suitable. Adjustments were not made to the fine gravel percentages for several reasons. Preliminary analyses showed that a high percentage of samples were below the suitability threshold prior to adjustments, thus adjustments were unnecessary. Unadjusted assessments are more conservative because they reflect worst case scenarios. The duration of embryo incubation can be lengthy (a conservative estimate is 3 months based on Moyle 2002), and it is likely that fines infiltrate gravels within redds during this time period. Therefore, a suitability assessment based on data that has been adjusted likely overestimates the degree of suitability, and only reflects gravel suitability immediately following redd construction.

The results from the fine sediment analyses suggest that fine sediments within gravels in the lower Feather River are suitable for incubating Chinook salmon and steelhead embryos, and likely do not limit the percentages of embryos surviving through emergence.

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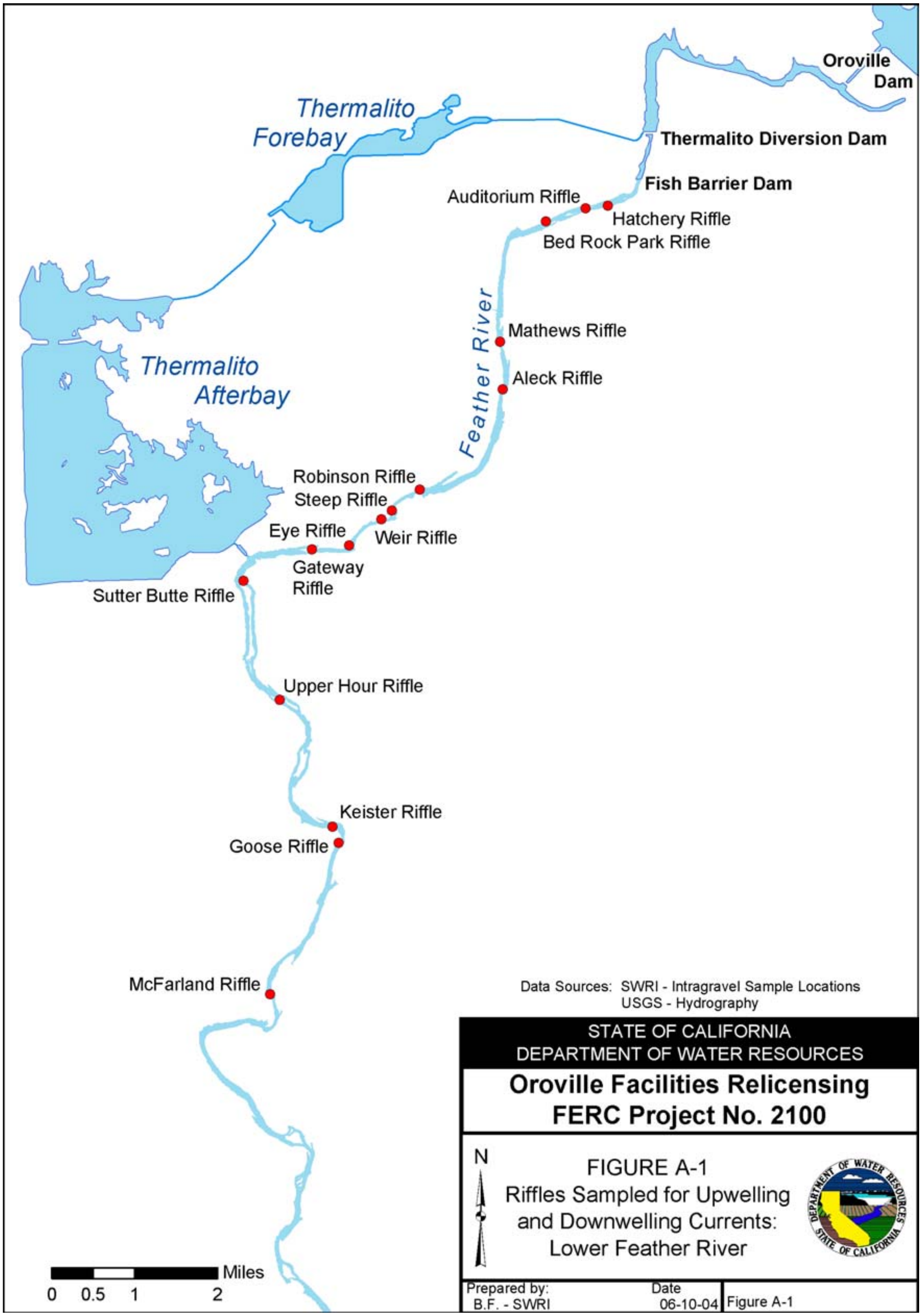
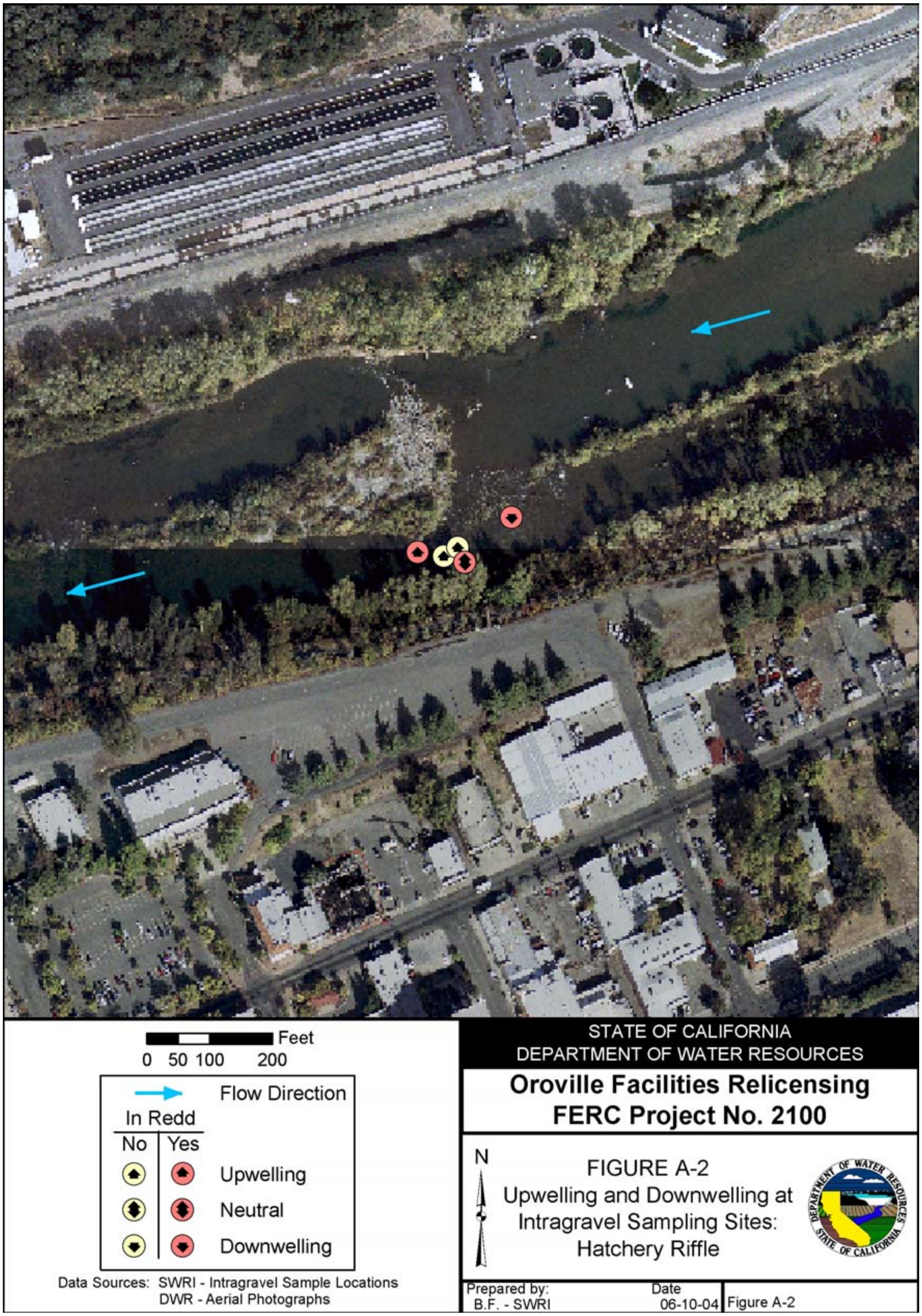
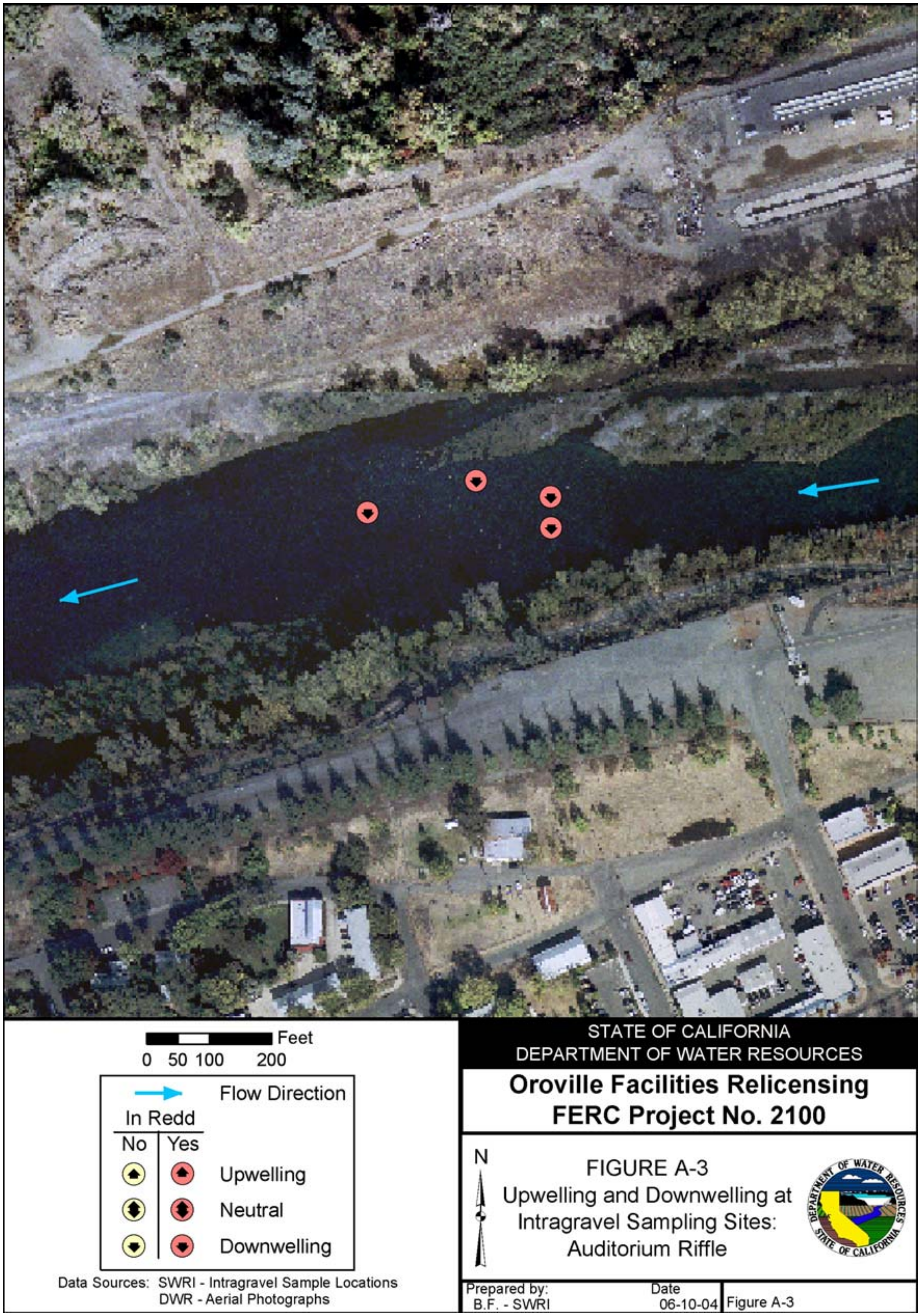
Appendix A

Upwelling and Downwelling Potential


Oroville
Dam
Thermalito
Forebay
Thermalito Diversion Dam
Fish Barrier Dam
Auditorium Riffle
Hatchery Riffle
Bed Rock Park Riffle
Feather River
Mathews Riffle
Aleck Riffle
Thermalito
Afterbay
Robinson Riffle
Steep Riffle
Eye Riffle
Weir Riffle
Gateway
Riffle
Sutter Butte Riffle
Upper Hour Riffle
Keister Riffle
Goose Riffle
McFarland Riffle
Data Sources: SWRI - Intragravel Sample Locations
USGS - Hydrography
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
Oroville Facilities Relicensing
FERC Project No. 2100
N
FIGURE A-1
Riffles Sampled for Upwelling
and Downwelling Currents:
Lower Feather River
Miles
0 0.5 1 2
Prepared by:
B.F. - SWRI
Date
06-10-04
Figure A-1


Feet
0 50 100 200
Flow Direction
In Redd
No
Yes
Upwelling
Neutral
Downwelling
Data Sources: SWRI - Intragravel Sample Locations
DWR - Aerial Photographs
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
Oroville Facilities Relicensing
FERC Project No. 2100
N
FIGURE A-2
Upwelling and Downwelling at
Intragravel Sampling Sites:
Hatchery Riffle
Prepared by:
B.F. - SWRI
Date
06-10-04
Figure A-2


Feet
0 50 100 200
Flow Direction
In Redd
No
Yes
Upwelling
Neutral
Downwelling
Data Sources: SWRI - Intragravel Sample Locations
DWR - Aerial Photographs
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
Oroville Facilities Relicensing
FERC Project No. 2100
N
FIGURE A-3
Upwelling and Downwelling at
Intragravel Sampling Sites:
Auditorium Riffle
DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA
Prepared by:
B.F. - SWRI
Date
06-10-04
Figure A-3

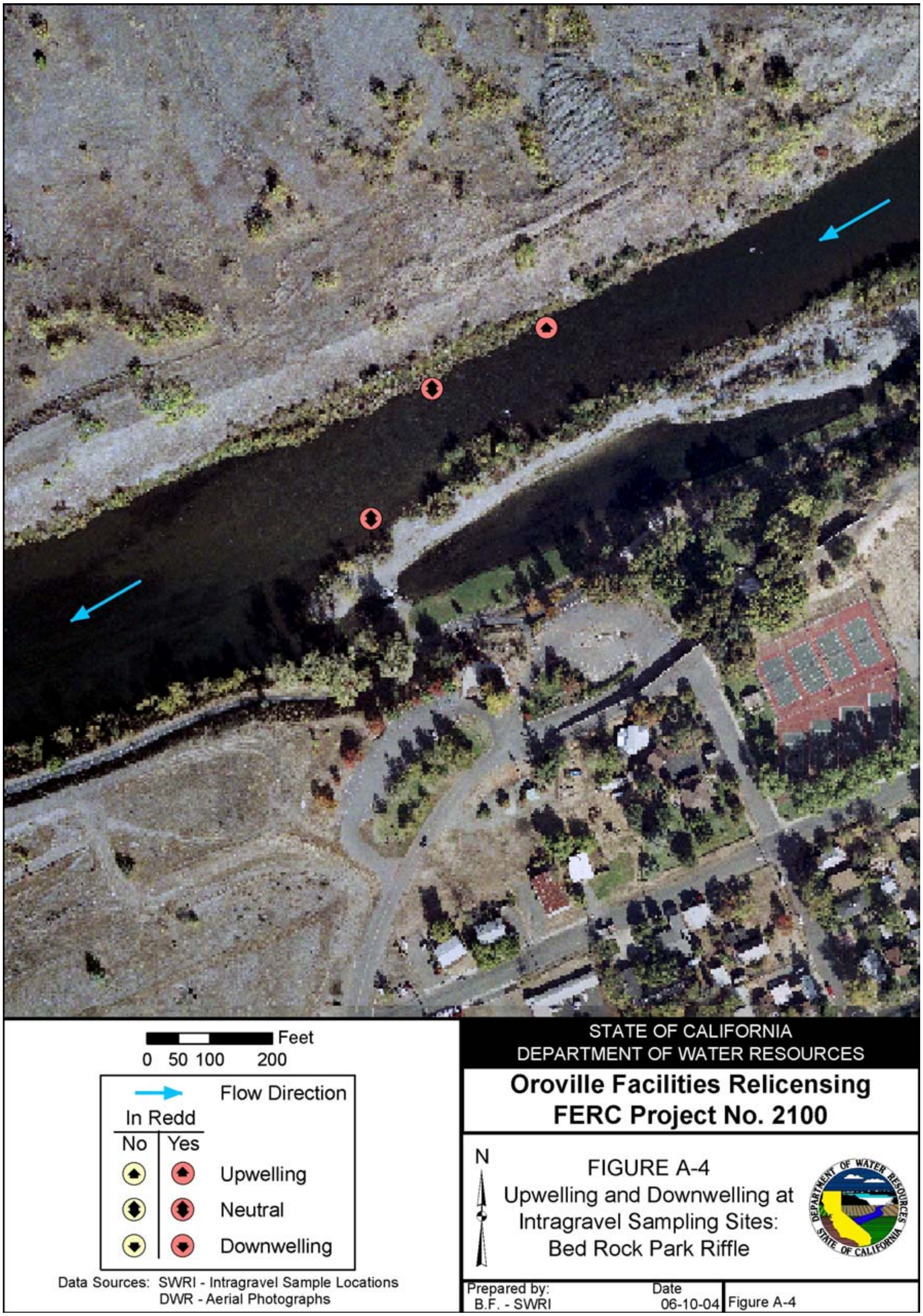
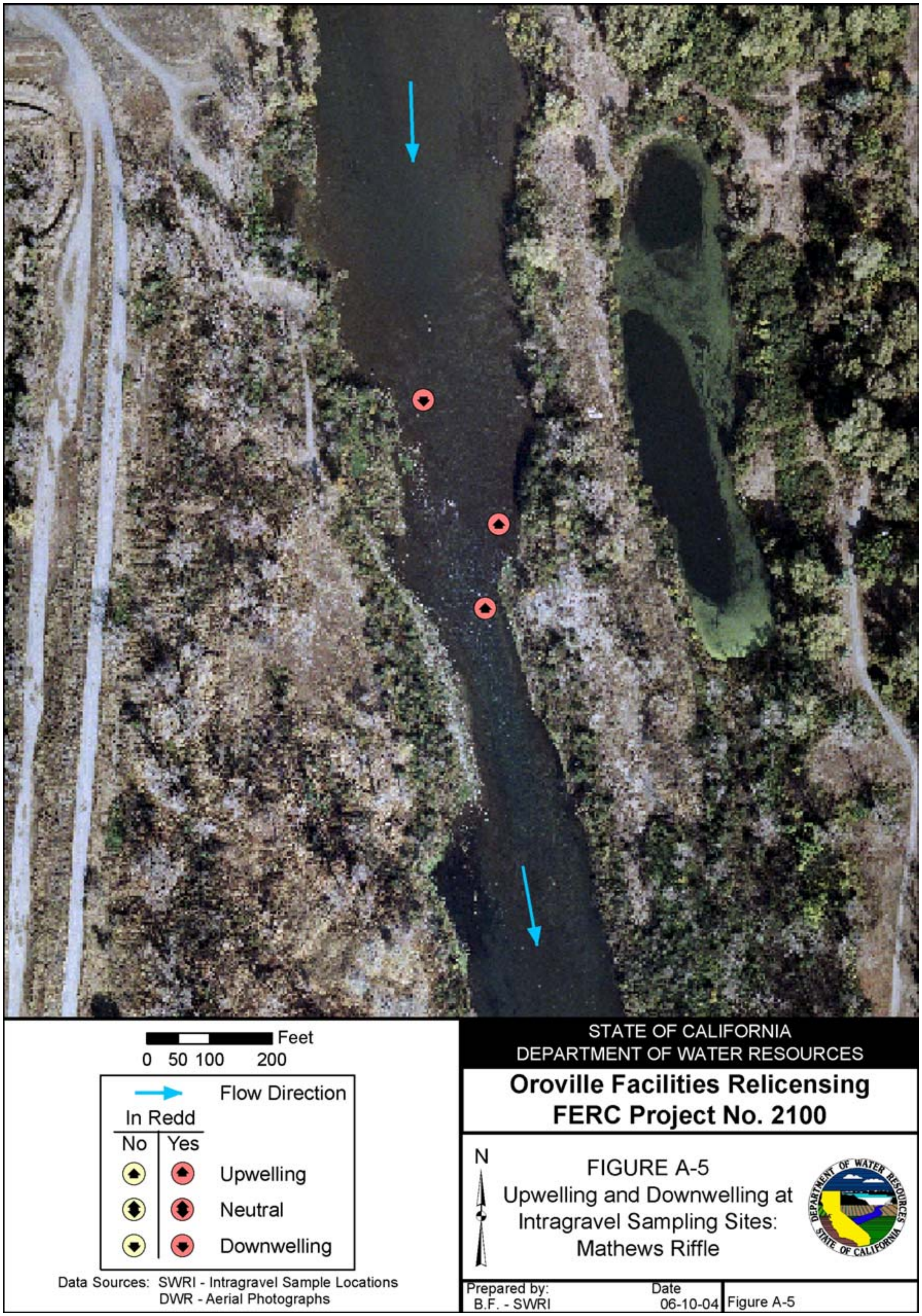


FIGURE A-4
Upwelling and Downwelling at Intragravel Sampling Sites: Bed Rock Park Riffle


Feet
0 50 100 200
Flow Direction
In Redd
No
Yes
Upwelling
Neutral
Downwelling
Data Sources: SWRI - Intragravel Sample Locations
DWR - Aerial Photographs
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
Oroville Facilities Relicensing
FERC Project No. 2100
N
FIGURE A-5
Upwelling and Downwelling at
Intragravel Sampling Sites:
Mathews Riffle
DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA
Prepared by:
B.F. - SWRI
Date
06-10-04
Figure A-5


Feet
0 50 100 200
Flow Direction
In Redd
No
Yes
Upwelling
Neutral
Downwelling
Data Sources: SWRI - Intragravel Sample Locations
DWR - Aerial Photographs
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
Oroville Facilities Relicensing
FERC Project No. 2100
N
FIGURE A-6
Upwelling and Downwelling at
Intragravel Sampling Sites:
Aleck Riffle
Prepared by:
B.F. - SWRI
Date
06-10-04
Figure A-6